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Niobium as an Alloying Element in Heat-Resisting Steels

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Within a certain range of temperatures the structural characteristics of heat-resisting steels may not remain constant. Carbide precipitation is an example of the structural change which influences the mechanical properties and affects quite definitely the corrosion resistance. Efforts have been made to overcome this precipitation by the addition of different alloys, among which is niobium. Recent investigations with this element have shown its value in steels for high-temperature service, and this review of recent work in this field indicates important possibilities for niobium steels.

IN his recent investigations concerned with the development of improved high-temperature resistant steels, E. R. Parker[1] has found that intermetallic compounds of Fe_2W, Fe_3Mo_2, Fe_3Nb_2, Fe_2Ta, and Fe_2Ti are considerably more stable at high temperature than carbides ; and he was able to show that alloys containing precipitates of such compounds possess a greater resistance to deformation and fracture than commercial alloys relying upon carbides for their strength. In view of the growing interest displayed in recent years in the use of niobium (columbium) as alloying element, Parker's experiments with a 3% Nb, 97% Fe alloy are particularly noteworthy.

Latest reports[2] indicate that similar investigations, conducted at the Kaiser-Wilhelm Institute in Germany, besides fully confirming Parker's findings, have already resulted in the development of low-alloyed niobium steels for high-temperature service. In view of the considerable practical import of this development a review of this work appears to be called for.

The equilibrium diagram for the Fe-Nb system according to H. Eggers and W. Peter[3] is given in Fig. 1. With Nb contents exceeding 0·5% an intermetallic compound is formed, the solubility of which greatly increases with rising temperature. It is therefore possible to harden FeNb alloys with more than 0·5% Nb by quenching from high temperature and subsequent tempering. The influence of the quenching temperature upon the hardness of an alloy containing 1·9% Nb is shown in Fig. 2. The causes of the steep rise in hardness exhibited above 900° C. are found in the different solubilities of Nb in the γ-phase and the α-mixed crystal, and in the γ-α transformation during quenching ; while the decline in hardness at temperatures exceeding 1,150° C. is explained by the fact that the alloy enters the δ-phase and that the homogeneous δ-mixed crystal is not subject to transformation during quenching to room temperature.

This view was fully sustained by microphotographic examination of three samples of the 1·9% Nb alloy, water-quenched from 1,000°, 1,200° and 1,300° C., respectively.

1 E. R. Parker, "The Development of Alloys for Use at Temperatures above 1,000° F." Trans. A.S.M., vol 28, 1940, p. 797.
2 F. Wever and W. Peter. "Precipitation Hardening and Creep Strength of Fe-Nb Alloys and Steels Alloyed with Niobium." Arch. F. D. Eisenhüttenwesen, vol. 15, Feb., 1942, p. 357.
3 H. Eggers and W. Peter, Mitt. K. Wilh. Inst. Eisenf., vol. 20, 1938, p. 199.
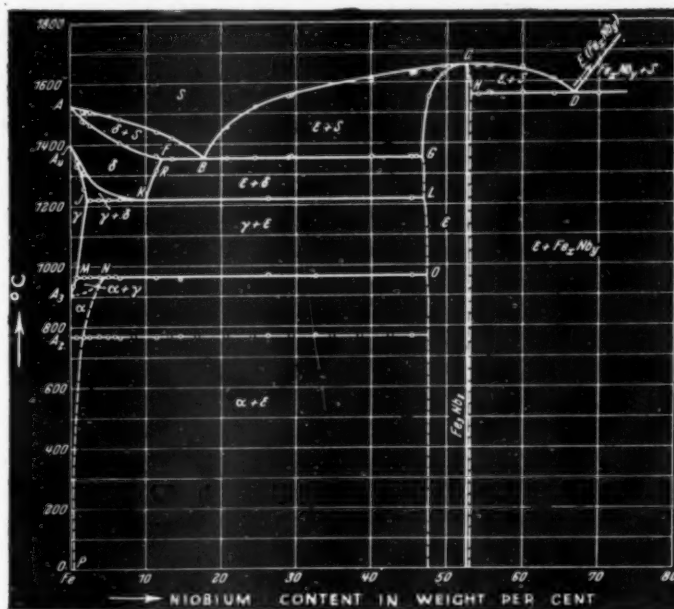
Fig. 1.—Iron-niobium equilibrium diagram.

The piece quenched from 1,100° C. clearly exhibited γ-α transformation and showed the presence of considerable amounts of intermetallic compound not yet dissolved at this temperature. The microstructure of the sample quenched from 1,200° C. was found to consist, in the main, of homogeneous δ-crystallites, and contained only small amounts of decomposed γ-phase. In consequence of this, the hardness of this piece was considerably below that of the piece quenched from 1,100° C., while still lower hardness was exhibited by the piece quenched from 1,300° C. and containing only homogeneous δ-crystallites.

The influence of the temperature of draw upon the hardness with various temperatures of quench is shown in Fig. 3. Here the optimum precipitation temperature is seen to lie between 600°–650° C. The greatest increase in hardness is obtained with the 1,300° C. quench. It is remarkable that the piece quenched from 1,100° C., in which a transformation hardening had taken place, also shows the effects of precipitation hardening manifested by

a further increase in hardness by 6Rc or 25 Brinell units. Iron-niobium alloys show a remarkable resistance to deformation. Thus the aforementioned 1·9% Nb alloy, quenched from 1,200° C. and subsequently tempered at 650° C., shows a creep strength of 38,370–42,600 lb. per sq. in. at 500° C., and of 46,860–49,700 lb. per sq. in. if quenched from 1,100° C.

approximately one-half of the Nb is contained as Nb carbide and the other half as iron-niobium intermetallic compound. In this case the original hardness of 75 Rb is increased to 28 Rc by quenching from 1,300° C. It should, however, be noted that the increase in hardness experienced with a temperature of draw range of 500°–600° C. is smaller than that of the 0·13% C—1·04% Nb material. Up to
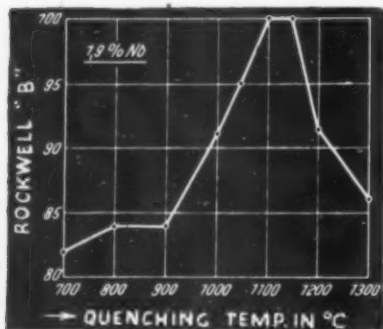
Fig. 2.—Influence of quenching temperature upon hardness of 1.9% Nb alloy.
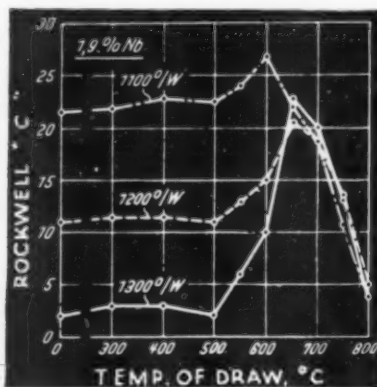
Fig. 3.—Influence of temperature of draw upon hardness of 1.9% Nb alloy water-quenched from various temperatures.
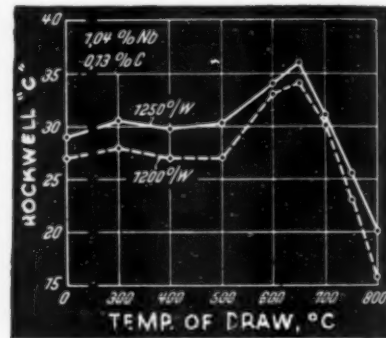
Fig. 4.—Inuflence of temperature of draw upon hardness of 0.13% C— 1.04% Nb steel after water-quenched from 1250° and 1200° C., respectively.

Investigations of the Fe-Nb-C system have established the occurrence of the same intermetallic compound.[4] In alloys of this kind the niobium first combines with the carbon present to a highly stable carbide.

This property of Nb finds extensive employment in stainless chrome-nickel steels in which the addition of Nb serves to reduce the danger of inter-crystalline corrosion.[6] It can also be used to reduce the hardness of chromium steels which must not be hardenable.[5] The quantity of Nb required for combining the carbon content amounts to eight times the carbon content.

The influence of the temperature of draw upon the hardness of a steel containing 0·13% C. and 1·04% Nb—that is, exactly eight times as much niobium as carbon—and water quenched from 1,200°–1,250° C., respectively, is illustrated by the graph reproduced in Fig. 4. By heating to high temperature the Nb-carbide can be made largely, or completely, to enter solution so that the steel can be hardened by subsequent quenching. Thus, the hardness can be increased from 87 to 99 Brinell with quenching from 1,100° C. With higher temperatures the amount of Nb carbides in solution is further increased, and the same steel quenched from 1,200° C. or 1,250° C. will, therefore, show still greater hardness. The remarkable resistance to tempering exhibited by hardened iron-niobium-carbon alloys of this type is due to the fact that the Nb carbides brought into solution at high temperature are precipitated only with the temperature of draw exceeding 500° C., hereby causing a considerable increase in hardness. A decrease in hardness occurs only when a temperature of 650° C. is exceeded. In order to achieve a maximum of precipitation hardening, a high temperature of quench must therefore be employed.

This high resistance to tempering can also be produced with steels in which the Nb percentage is more than eight times that of the carbon. Steels of this type contain the intermetallic compound of iron-niobium in addition to the niobium carbide, and therefore show the phenomena connected with the presence of the intermetallic compound. Fig. 5 shows the temperature of draw *versus* hardness curves of a steel with 0·05% C. and 0·97% Nb, in which

these high-quenching temperatures the structure of these steels is said to remain fine-grained, the shifting of the grain-growth limit to temperatures above 1,300° C. being due to the fact that a part of the niobium carbides and intermetallic compounds remains undissolved.

The important influence exerted by the carbon content upon the creep strength is evidenced by the graph reproduced in Fig. 6. In this chart, which refers to a steel with approximately 2% Nb content, the creep strength[7] is seen to show a rapid rise when the Nb/C ratio is made to exceed the aforementioned value of 8 : 1. A steel containing approximately 2% Nb and 0·23% C, in which the entire Nb contents are contained as Nb carbide, is seen to possess a creep strength of only 42,600 lb. per sq. in. But if the carbon content is lowered to 0·19%, corresponding to a Nb/C ratio of 10 : 1, a creep strength of 67,000 lb. per sq. in. was recorded. This is due to the fact that the increased Nb/C ratio leads to the appearance of the intermetallic compound in addition to the Nb-carbide. It is therefore evident that the beneficial effect of Nb upon creep strength is due to the existence of the intermetallic compound, which is in complete agreement with Parker's findings. Thus, for instance, a steel containing 1·04% Nb and 0·13% C, in which the entire carbon contents occur as Nb-carbide, possesses a creep strength of 42,600 lb. per sq. in. at 500° C.: while a material with 0·05% C and 0·97% Nb, containing more than one-half of its Nb content as intermetallic compound, exhibits a creep strength of 69,580–71,000 lb. per sq. in. at the same temperature.

An examination of the influence of the temperature upon the creep strength conducted on a 0·14% C—2·07% Nb steel showed that a rapid decrease in creep strength occurs if the temperature exceeds 550° C. This appears to indicate an incipient agglomeration of the intermetallic compound with a resultant loss in optimum dispersal. The notched-bar impact strength of a 0·14% C— 2·07% Nb steel after quenching from 1,300° C. was found to be only 14·46 ft.-lb. As Fig 7 shows, a minimum impact strength of 7·23 ft.-lb. is registered after tempering at about 535° C. With further increases in the temperature of draw a steep rise in impact strength takes place. But it is unfortunate that the attainment of more satisfactory values of impact strength with tempers at 550° C. and

4 H. Eggers and W. Peter, *Mit. K. Wilh. Inst. Eisenforsch.*, vol. 20, 1938, p. 205.
5 E. Houdremont, *Einführung in Die Sonder Stahl Kunde*, 1935, p. 550; *see also* R. Franks, W. O. Binder and C. R. Bishop: " The Effect of Molybdenum and Columbium on the Structure, Physical Properties, and Corrosion Resistance of Austenitic Stainless Steels," Trans. A.M. Soc. Metals, vol. 29, 1941, p. 39.
6 German patent No. 667,630, July, 1938.

7 Defined as the load producing 10 × 10⁻⁴% permanent elongation per hour during the 25–35th hours of the test.

higher coincides with a serious decrease in creep strength, and also in the yield point.

Increased yield point and creep strength, therefore, must be purchased at the expense of decreased notched-bar impact strength. It is interesting to note that impact tests conducted on plain bars without notch showed surprisingly good impact values. Thus, tempered Nb steels cannot be considered as brittle *per se*, but only highly sensitive to the effect of notching.
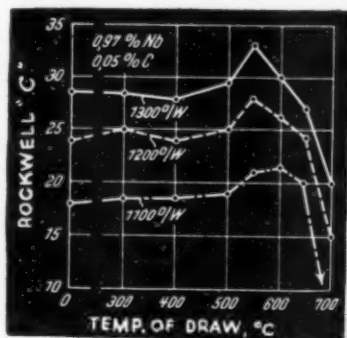
Fig. 5.—Influence of temperature of draw upon hardness of 0.05% C —0.97% Nb steel after water-quench from 1300°, 1200° and 1100° C., respectively.
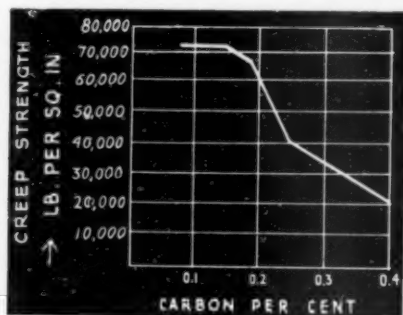
Fig. 6.—Creep strength of 2% Nb material in tempered state versus carbon content.
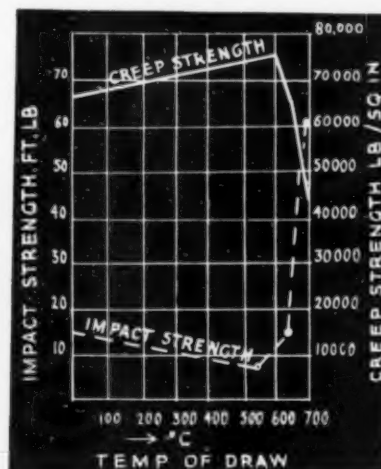
Fig. 7.—Influence of temperature of draw of a 0.14% C—2.07% Nb steel, water-quenched from 1300° C., upon creep strength and notched-bar impact strength.

The aforementioned method of heat-treatment can also be applied to alloyed steels provided the Nb content is made higher than eight times the carbon percentage. A steel with 0·11% C—0·72% Cr and 1·9% Nb, quenched from 1,300° C. and subsequently tempered at 600° C., was found to possess a creep strength of 78,100—79,520 lb. per sq. in. at 500° C.; but its notched-bar impact strength amounted to only 7·23 ft.-lb. For a steel containing 0·17% C, 0·88% Mo, 0·72% Cr, and 1·95% Nb, a creep strength of 63,900—71,000 lb. per sq. in. at 500° C. was recorded.

Additions of niobium to austenitic high-temperature resistant steels result in a considerable improvement of their creep strength. After water quenching from 1,150° C., a steel with 0·14% C, 18% Cr, 8% Ni, and 2·7% Nb exhibited a creep strength of 31,240–32,660 lb. per sq. in. at 600° C. The rule that the Nb content must be more than eight times greater than the carbon content in order to effect a considerable improvement in the creep strength applies to this class of steels also. But there exists a certain upper limit for the Nb content insofar as the restrictive influence of niobium upon the γ region tends to effect pronounced changes in the structure of highly alloyed Cr-Ni steels. Thus the addition of 2·7% Nb to an 18% Cr–8% Ni steel results in the occurrence of ferritic α-mixed crystals along with the austenitic γ-mixed crystal, their occurrence growing in intensity with increasing Nb percentage. Restitution of the austenitic character of the steel can be effected only by increasing the nickel content, as given in the subjoined table :—

CREEP STRENGTH OF AUSTENITIC CR—NI STEELS ALLOYED WITH NIOBIUM.

Steel No.	C, %.	Si, %.	Mn, %.	Ni, %.	Cr, %.	Nb, %.	Creep Strength, lb./sq. in. at 600° C.	700° C.
1	0·12	0·78	0·52	15·4	16·5	0·8	24,140	12,780
2	0·12	0·82	0·49	15·2	16·0	2·76	26,980	17,640

A critical evaluation[8] of the various tests has led to the conclusion that with a 2% Nb content a maximum increase of 35% in strength can be obtained with a Nb/C ratio of 8 : 1, whilst ratios of 10 : 1, 16 : 1, and 25 : 1 will improve the creep strength by 8%, 5% and 4%, respectively.

8 W. Peter. "The Effect of Niobium Upon the Creep Strength of Steels," *Arch. F. D. Eisenhüttenwesen*, vol. 15, 1942, p. 364.

Similar improvements can be achieved with steels alloyed with 1% Nb. Highest creep-strength will be obtained if the temperature of draw lies above the temperature zone of maximum precipitation hardening. This will ensure completion of precipitation and thus obviate further precipitation under operating conditions. In this way it is possible to obtain the degree of dispersion most suitable from the aspect of creep strength.

Tests conducted on a 0·19% C—1·99% Nb steel are said to have shown that heat-treatment should not be carried out with a view to obtaining the greatest possible degree of precipitation hardening, as this will lead to a deterioration in the creep strength. For steels of this composition the precipitation range lies between 550°-600° C. Pieces tempered at this temperature, and subjected to a load of 63,900–72,420 lb. per sq. in., were found to fracture without previous deformation after 2–6 hrs.; but if they were tempered at 650° C., a creep strength of 68,160–71,000 lb. per sq. in. at 500° C. could be registered. A good insight into the influence of quenching temperature and quenching speed can be obtained by reference to the subjoined table :—

INFLUENCE OF THE HEAT-TREATMENT UPON THE CREEP STRENGTH AT 500° C. OF A STEEL CONTAINING APPROXIMATELY 0·13% C AND 2% Nb.

Method of Heat-treatment. Quench.	Draw.	Creep Strength in lb./sq. in.
1,300° C. water	1 hr., 600° C. air	73,840
1,300° C. air	—	59,640
1,200° C. water	1 hr., 600° C. „	68,160
1,200° C. air	—	48,280
1,100° C. water	1 hr., 600° C. „	56,800
1,100° C. air	—	45,440
1,000° C. water	1 hr., 600° C. „	45,440
950° C. water	1 hr., 600° C. „	31,240
950° C. air	—	17,040

In these tests, which were made on pieces measuring 20 × 20 × 185 mm., creep strength was defined as the specific loading resulting in a permanent deformation of 0·2% after 45 hours of loading. Under these conditions creep rates of $0·5$–2×10^{-4}% per hour were observed during the 25–35th hours of the test run. Similar results are reported with regard to a steel containing 0·07% C and 0·85% Nb.

It has been mentioned before that considerations of creep strength make it imperative to choose a Nb/C ratio in excess of 8 : 1; while the quenching temperature must be so determined that quenching is effected from the γ-zone. Any increase in Nb above 2% is considered useless, since it will not be accompanied by any further improvement in creep strength. The employment of high-quenching temperatures exceeding 1,100° C. must be considered a

INFLUENCE OF THE NIOBIUM CONTENT UPON THE MECHANICAL PROPERTIES OF ROLLED STEEL WITH 0·14% C, NOT SUBJECTED TO HEAT-TREATMENT.

Composition.	0·14% C, 0·45% Si 0·37% Mn, 0·62% Nb Nb : C = 4 : 1		0·14% C, 0·34% Si 0·33% Mn, 0·97% Nb Nb : C = 7 : 1		0·44% C, 0·35% Si 0·3% Mn, 1·46% Nb Nb : C = 10 : 1		0·14% C, 0·34% Si 0·37% Mn, 2·0% Nb Nb : C = 14 : 1	
Rolling temperature, °C.	1,200	1,000	1,200	1,000	1,200	1,000	1,200	1,000
Ultimate tensile strength, lb./sq. in.	76,680	68,160	76,680	56,800	66,740	56,800	69,580	62,480
Stress producing 0·2% permanent elongation at room temperature, lb./sq. in.	59,640	46,860	59,640	26,980	36,920	21,300	31,240	22,720
Reduction in area, %	67	74	73	79	77	79	74	77
Elongation, %	28	34	27	40	32	38	29	37
Notched bar impact strength, ft.-lb.	108·5	151·8	108·5	216·9	144·6	151·8	108·5	151·8
Creep strength at 500° C., lb./sq. in.	17,040	9,940	17,040	11,360	25,560	14,200	26,980	17,740
Creep rate during 25–35th hour, 10⁻⁴%/hr.	8·5	11°	8	10	1·5†	1·0‡	1·5	0·5§
Permanent elongation after 45 hours, %	0·094	0·125°	0·091	0·121	0·352†	0·284‡	0·154	0·225§

° At 11,360 lb./sq. in. † At 28,400 lb./sq. in. ‡ At 15,620 lb./sq. in. § At 18,460 lb./sq. in.

distinct disadvantage from the practical point of view. It is, therefore, most interesting to note that according to Peter[*] a reduction in quenching temperature to 1,000° C. can be achieved by the inclusion of approximately 1% Si. This will result in creep strength values exceeding 71,000 lb. per sq. in. at 500° C.

In order to ascertain whether the influence of the Nb/C ratio upon the creep strength extends to a rolled material not subjected to heat-treatment, a number of steels with 0·14% C and various Nb percentages were investigated. the temperature of rolling varying between 1,000° and 1,200° C. The reduction to which these pieces were subjected in the rolling process is given as 35%, the final dimensions being $45 \times 20 \times 1,000$ mm. As evidenced by the data given below, an increase in the Nb/C ratio from 7 : 1 to 10 : 1 results in an improvement in creep strength by approximately 50%, thus proving the existence of the critical 8 : 0 ratio.

The table also shows that an increase in rolling temperature from 1,000°–1,200° C. leads to a considerable increase in creep strength at 500° C.; but the decrease in the creep rate during the 25–35th hours is by no means equalled by the decrease in permanent deformation reached after the 45th hour. An increase in the Nb : C ratio above 8 : 1 is seen to lead to a narrowing down of the margin existing between the creep strength at elevated temperature and the 0·2% permanent deformation limit at room temperature. This effect must be considered to be due to the action of the intermetallic compound. The stronger creep delaying action of the latter, as compared to that of the Nb carbides, is closely evidenced by the considerable reduction in the creep rate obtaining during the 25–35th hours. Steels with a Nb : C ratio larger than 10 : 1 were found to show no tendency to deformationless fracture. Nor did the results of specially made long-time creep tests, extending to as much as 6,000 hours, give any indication of incipient embrittlement.

From the equilibrium diagram it was concluded that a niobium content of less than 2% permits of the use of high quenching temperatures without producing the δ-crystallites. This was fully verified by a number of tests conducted on two alloys, the one containing 0·96% Nb and 0·01% C, and the other 1·38% Nb with 0·02% C, the tests yielding creep strengths as high as 68,160–71,000 lb. per sq. in. at 500° C. The creep strength was determined on the basis of

[*] loc. cit.

0·2% permanent deformation after 45 hours. The creep rate was found to lie between $0·5 - 4 \times 10^{-4}$% per hour during the 25–35th hours. These results clearly indicate that a reduction in Nb content to 1% will not effect a reduction in creep strength, provided the carbon content is also reduced to the greatest possible extent. Incidentally, a comparison of the results obtained with the combination of 1% Nb with 0·01%, 0·05%, and 0·13% C again pointed to the important influence of the inter-metallic compound upon the creep strength. The actual test data are reproduced below.

INFLUENCE OF THE CARBON PERCENTAGE UPON THE CREEP STRENGTH AT 500° C. OF STEELS CONTAINING 1% Nb.

Nb, %.	C, %.	Si, %.	Mn, %.	P, %.	S, %.	Creep Strength, lb./sq. in.	Creep rate during 25–35th hour in 10⁻⁴% per hour.
0·96	0·01	0·41	0·31	0·011	0·01	71,000	2·0
0·97	0·05	0·34	0·40	0·016	0·032	71,000	2·5
1·04	0·13	0·5	0·24	0·022	0·022	42,600	9·0

These data fully prove that the increase in Nb carbides, and the consequent decrease in the intermetallic compound caused by an augmentation of the carbon content, are of decisive influence upon the creep strength. With regard to the favourable influence of increased carbon content in steels containing 2% Nb and more, it should be noted that this is solely due to the fact that the increased carbon content tends to shift the γ-δ transformation into higher temperature ranges, and hereby permits the employment of higher temperatures of quench without exceeding the upper limit of the γ-region.

PHYSICAL PROPERTIES OF Fe-Nb ALLOYS AS INFLUENCED BY THE SULPHUR CONTENT.

Composition.	0·02% C, 0·97% Si 0·06% Mn, 0·008 P 0·004% S, 0·22% Nb		0·02% C, 1·09% Si 0·04% Mn, 0·028 P 0·028% S, 0·34 Nb		0·03% C, 1·0% Si 0·3% Mn, 0·017% P 0·38% S, 0·3% Nb	
Water quench, °C.	1,200	1,000	1,200	1,100	1,200	1,100
Temperature of draw, °C.	600	600	600	600	600	600
Ultimate strength at 20° C., lb./sq. in.	103,080	88,040	103,660	89,460	110,760	79,520
0·2% permanent deformation limit at 20° C., lb./sq. in.	89,460	73,840	86,620	72,420	97,980	65,320
Elongation at 20° C., %	21	32	18	20	17	27
Reduction of area at 20° C., %	77	82	60	70	42	58
Notched bar impact strength at 20° C., ft.-lb.	7·23	72·3	14·46	36·2	13·0	54·3
Creep test at 500° C.,—						
Loading, lb./sq. in.	65,160	53,960	49,700	42,600	35,500	21,300
Creep rate in 3rd–6th hour, 10⁻⁴%/hr.	15	8·3	46·7	40	165	410
Creep rate in 25–35th hour, 10⁻⁴%/hr.	2	1	6·5	6·5	—	3·0
Permanent elongation after 45 hr., %	0·272	0·229	0·149	0·138	—	0·2

Once it had been found that the simultaneous reduction of the Nb and C contents provides the solution of the problem of developing creep resistant steels with low Nb percentage, a systematic enquiry as to the minimum permissible Nb content could be instituted. This was found to lie between 0·5–0·7% Nb content. The erratic decreases in creep strength registered for steels containing less than 0·5% Nb made it apparent that at these low Nb percentages the beneficial effect of the intermetallic compound was negatived by some other factor. From a comparative study of creep strength values and analyses of a number of low Nb steels, it was finally found that this adverse influence arises from the sulphur content of the material. In the course of the investigations it was finally found that a

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The Trend of Electroplating Development

THE deposition of a metal on another substance, usually another metal, by electro-chemical action, either for the purpose of protecting the latter metal from corrosion or for decorative purposes, is a highly specialised process, but the products of the process have become so familiar to everyone that developments are effected almost unnoticed. Actually, the electroplating industries have undergone a most interesting change as a result of the war, which has been in the direction of producing protective deposits rather than those produced, in the main, for decorative purposes ; in addition, the process is being applied in the production of tinplate, as is described elsewhere in this issue by Mr. Hoare, to conserve tin, without unduly sacrificing the degree of protection the thin coating affords. In a recent address to the Midlands Centre of the Electrodepositors' Technical Society, Dr. S. Wernick outlined this industry in 1939, discussed the effect of development on war finishes, the role of metal-finishing to-day, and hazarded an opinion regarding conditions likely to be encountered when the war is over. His views are noteworthy.

During 1939, for instance, before the outbreak of war, several interesting new processes in the metal finishing industry had either reached an advanced development stage or had actually attained the production point. Perhaps the most interesting, because of its immediate practical importance, was the bright nickelplating process. This had certainly reached the production stage, and the benefits of this process were gradually spreading throughout the industry. Probably the most popular of these processes were those based on the alloy deposit nickel-cobalt. This had proved to be a dependable process and had not only been applied successfully to brass and copper parts, but also, to a limited extent, to steel as a basis metal, and to a lesser extent to zinc base die-castings.

The deposition of alloys in general was receiving considerable attention and much useful work had already been published, not only on binary, but even ternary alloy deposits. One of the most interesting of the binary alloys which had achieved an advanced state of development was white bronze or, in other words, a high tin-copper alloy, one of the most outstanding features of which was the remarkable whiteness of the finish—this latter approaching that of silver to a very considerable degree. White bronze as an alloy, of course, is not new, since it was well known to the Egyptians thousands of years ago, but the deposition of this alloy marks an interesting stage in electroplating development.

Another process which was receiving increasing attention from metal finishers was that based on the anodic oxidation of aluminium and its alloys. In this case, not only have we an electrolytic process which produces a highly decorative surface effect, but this finish is simultaneously in the highest degree protective of the basis metal. The decorative possibilities are literally almost

unlimited, as almost any shade of dye can be incorporated in the surface and the most beautiful effects have been produced, the commercial possibilities of which are far from being exhausted.

Still another interesting process which was on the verge of reaching the point of practical application is that of electrolytic polishing. The possibilities of polishing, by electro-chemical methods as against manual methods, such metals as aluminium, nickel, etc., open up a very important field to the electroplater. A very considerable amount of protective metal plating was also being carried out, this including cadmium and zinc plating, while with regard to the latter the production of bright zinc plating was also arousing much interest.

Not less important, perhaps, were the developments in the production of improved types of plant to deal with plating processes of all kinds, both old and new. The increased plating speeds and mass production methods have necessitated the alteration and design of automatic plating plant, comprising the whole series of cleaning and plating operations. Power plant also had undergone a highly important development in the advent and steady improvement of rectifier equipment.

Effect of Development on the War Finishes

There is a general impression that much of this plating development has gone into cold storage for the duration of the war, and at first sight, considering the preponderance of plated work which was related to chromium finishing, this view does not appear to be far from the truth. Closer investigation, however, proves quite definitely that it is fallacious and that practically every one of the processes and developments has its direct prototype, or at least has an important influence on the metal finishes of to-day, and which may be called war finishes.

Thus, for example, although little bright nickelplating is being carried out to-day, the technique which resulted in the perfection of bright nickel as a process is copied and utilised to a considerable extent for the deposition of very thick deposits of nickel (comparative with decorative nickel) largely for building up parts which have either been wrongly machined or worn in service. This does not mean that bright nickel deposits are being produced for building-up purposes, because undoubtedly the most suitable type of nickel, where high adhesion to the basis metal and prolonged periods of deposition are essential, is produced in a dull or matt condition, obtained from a Watts' type of nickelplating solution ; such nickel is likely to be considerably less stressed than bright nickel. But the technique employed in the production of bright nickel deposits has taught us, in no undecided manner, that a very high state of purity of the nickel solution is essential. This, in turn, has necessitated considerable improvements in the plant employed for filtering the nickel solution and this experience, when directly incorporated into the production of heavy nickelplating, has very much helped to improve and also maintain the quality of deposit which is most suitable for this purpose.

With regard to anodising, the experience gained in the operation both of the chromic acid and sulphuric acid processes in pre-war days have proved to be of great benefit under present conditions when the total output of anodised aluminium components has increased out of all proportion to original estimates. It is safe to say that the number of anodising plants in the country to-day is many times that which satisfied our peace-time needs.

Again, there have been big increases in the output of cadmium- and zinc-plated components for all types of armament material. Cadmium has proved to be a very popular finish with all three services. One may almost say that the enthusiasm for cadmium rather overstepped its real sphere of usefulness, particularly as when certain Government departments were specifying cadmium as a finish not only on ferrous, but also for non-ferrous materials. However, the more recent shortage of cadmium supplies has resulted in a considerable swing-over to zinc plating as a protective finish on ferrous material. Although this change was made reluctantly in many instances, it is doubtful whether we have suffered in protective efficiency in any but a small percentage of instances. Indeed, it is probable that on the whole there has been a distinct gain.

A further important finish which has been increasingly specified by Government departments is tin-plating. Here again there can be no doubt at all that very considerable benefit accrued as the result of researches which were carried out simultaneously in America and this country on the efficiency of tin-plating solutions during the years immediately prior to the war. As a result, the old inefficient tin-plating bath was replaced by the stannate electrolyte. The latter process has taken a great deal of the uncertainty out of commercial tin-plating.

Even in such a mundane process as metal cleaning, the methods used in the preparatory cleaning in electroplating practice have found an enormous application in treating all kinds of steel and brass components required in armament production. It has been found an immense benefit to make use of such processes in close liaison with the heat-treatment which such components have to receive in course of manufacture. The removal of scale produced by oxidation in the furnaces during heat-treatment is being carried out by numerous metal-cleaning plants of the chemical type throughout the country, and such plants are also being employed for removing oil, grease and organic matter generally. In the latter connection, an important aspect of this work is that it has very considerably relieved the production of organic degreasing material, the most popular of which is, of course, trichlorethylene. Restrictions on the supply of the latter have been very well met by the use of chemical degreasing methods developed and improved in pre-war days in plating practice.

The Role of Metal Finishing To-day

One could go on multiplying instances where the processes in use to-day can be shown to be but a further development and adaptation of the processes employed in pre-war times. The probability is that the total volume of work handled by the metal finishing industry to-day, far from having diminished as compared with its output in pre-war days, has in fact very largely increased. It is safe to say that never were so many manufactured metal parts being produced which required some degree of surface protection or treatment.

Among the finishes which have received a noticeable impetus as a result of present-day demands are those produced by immersion as distinct from electrolytic finishes. These are having a very considerable vogue at present, and include the Parkerising, Bonderising and Cosletting processes for ferrous material, and granodising and chromating for zinc base material. A considerable demand has also arisen for black immersion finishes on steel. All in all, the contribution of the metal finishers to the war effort is something of which the industry may well be proud.

Many of the requirements of the Services are particularly exacting and difficult, thus equipment may have to stand up to the saline atmosphere of the sea or the hot humid atmosphere of the desert, and it is largely the charge of the metal finisher that no mechanism shall break down through corrosion. How well the industry carries out its work is indicated by the very few complaints which are made of the performance of the applied finishes under these most exacting conditions.

Post-War Developments

There cannot be any doubt that there will be a general desire after the war to return to decorative plating. Indeed, there is a good possibility that with the shortage of articles of the luxury and semi-luxury type which war conditions are bringing about to an increasing extent there will be something in the nature of a boom period when articles of this type will be wanted in large quantity and wanted rapidly. However, it is not anticipated that the moment the war is over there will be a general removal of all restrictions as they affect plating to-day. It is more likely that the demand by the public for decorative plating will not be satisfied for some considerable period. The probability is that it will take time before various materials in short supply at the moment are again plentiful.

An additional possible factor, too, is that there will not be an immediate wholesale change-over from war-time to peace-time metal finishing, since one may well imagine that production of armaments will not be immediately halted, and may in fact continue, although on a reduced scale, for some considerable time after the war. It is unlikely that we shall make the mistake that we did after the last war in so far as armament reduction is concerned. However, one may deduce that there will be an appreciable amount of decorative work available for the metal finisher.

Many will remember that there was a great deal of discussion during the 10 or 15 years prior to the war regarding the desirability of electroplating being produced on a specification basis. There were, undoubtedly, many difficulties in the way, arising very largely through competition on the part of the small minority of electroplaters who were out to obtain quick returns and had no pride whatever in their product or in the industry. The advent of specifications which were issued by Government departments immediately cut across the whole of this controversy and forced the industry to supply electro-deposits and finishes the quality of which had to exceed an irreducible minimum.

A Specification-minded Industry

The benefits of adhering to a specification have now become manifest in many quarters where previously there was considerable doubt not only of the practicability of adhering to a specification, but also the desirability of doing so. It is hoped that if we do not gain anything else as a result of the war, we shall at least not lose this specification-mindedness which now imbues the industry in such a healthy fashion.

Already a considerable amount of work has been done in the way of standardisation of materials used by the electroplater. It is particularly gratifying to observe that the bulk of this work not only originated through the ægis of the Electrodepositors' Society, but was also carried out by its own Standards Committee, which was set up some years ago and has done such excellent work in close co-operation with the British Standards Institution. As a result there are now in existence a number of issued specifications carrying the authority of the British Standards Institution covering important chemicals and anodes employed in plating baths. These have been accepted by the trade, and at the cessation of hostilities the time will be ripe for an immediate continuation of this good work which should result, in due course, in the drawing up of specifications to cover electroplating processes and metal finishes generally.

Heat-Treatment Response in Certain Non-Alloy Steels

By Bernard Thomas, F.Inst.P., F.Inst.F.

Evidence is given by the author that the properties of carbon steels may vary considerably on heat-treatment according to the manganese content, but in weighing up the potentialities of a given type the content of other elements require consideration to arrive at some standard hardening value.

ONE of the objects of the En. series of steels is to provide alternatives for existing specifications, with a view to reducing consumption of the alloying elements nickel and chromium. This reminds us that so long have we been accustomed to choosing 4 S11 or S 69, etc., for our requirements that we have almost forgotten what straight carbon steels can do. The object of these remarks is to discuss how the properties of the higher carbon steels may vary even when the other elements, particularly manganese, fluctuate.

In a "straight" carbon steel containing essentially only the five common elements, carbon, manganese, sulphur, phosphorus and silicon, only the first two named are regarded as being of value in the provision of mechanical requirements upon heat-treatment. While quite high ultimate strengths are possible on quenching, the nature of the latter may be, of necessity, so drastic as to cause, firstly, risk of quench cracks, and, secondly, Izod impact figures of negligible value.

To improve impact figures by removal of brittleness, tempering is necessary to obtain a sorbitic condition. This naturally reduces the ultimate strength, and the usual way to maintain the latter property is to introduce a higher percentage of carbon.

Unfortunately, as the carbon increases so must the manganese decrease correspondingly, as otherwise a coarse-grained and brittle product is forthcoming. While low carbon specifications such as the old DTD. 126A (En. 14) may have manganese present up to 1·75%, and be capable of yielding in the experience of the writer up to 45 tons ultimate stress with an Izod figure of 112/115 ft.-lb., the higher range of En. 9 calls for a restriction of manganese to 0·75%.

Normally, En. 9 is not used in the heat-treated condition, but there is no reason what it should not be so employed, as with proper care in its handling impact values of 30 ft.-lb. minimum are obtainable with an ultimate stress of 50 tons.

For the purpose of these notes five steels were studied, all of which conform to En. 9, with the exception of the manganese content in two instances. It should be explained that En. 9 is described as a "55" carbon steel. The compositions of the five steels in question are given in Table I.

TABLE I.
COMPOSITIONS OF FIVE STEELS TO EN.9 SPEC.

Reference No.	N.	NA	R.	PA.	P.
	%	%	%	%	%
Carbon	0·50	0·53	0·50	0·52	0·51
Manganese	**0·51**	**0·60**	**0·72**	**0·80**	**0·92**
Sulphur	0·051	0·045	0·025	0·023	0·034
Phosphorus	0·047	0·043	0·034	0·037	0·040
Silicon	0·157	0·165	0·171	0·159	0·163
Hardening value	**0·50**	**0·53**	**0·66**	**0·71**	**0·79**

The steels were chosen deliberately in view of their rising manganese content, and it is for this reason that the percentage present of that element is shown in bolder type to draw attention.

Normally speaking, there is so little difference between the five carbon contents that the average user would regard them as the same. In practice, however, considerable difference exists, which led the writer to carry out bend tests similar to those described in an earlier issue.[*]

For the benefit of those readers who may not be familiar with the method of bend testing employed, it can be described as being carried out in a device consisting of a jig wherein the strips for test could be laid across bearers having 6-in. centres, and leaving the portion in between unsupported. Loading was applied by means of a standard Brinell hardness machine of the 3,000-kg. type, but using special weights calibrated to apply loads from 50 kgs. upwards.

The movement of the strips under load actuated a pointer having an eccentric axis. The reverse end of this pointer moved along a scale graduated from 0 to 1·0 in. by 0·01 in. By estimating half the smaller divisions it was possible to obtain readings with fair accuracy to 0·005 in. of deflection.

Strips for test were rolled to desired gauge, usually around ⅛ in. thick, and subsequently machined down to 7 in. long by 1 in. wide in all instances. Care was taken always to ensure that dimensions were correct, and also that the gauge was the average of four readings minimum, owing to the influence which even slight differences could exert.

A specially manufactured V-shaped tool with rounded apex was the means of making contact with the strips, a male portion carrying a thread being screwed into the place which carries normally the ball-holder in the Brinell machine.

The method of testing was to mount a strip in the jig, bring the nose of the bending tool just into contact with it, without actually applying any load, and then ensure the pointer was at zero on the scale. Load was then applied until the weight-arms lifted. In this respect it was not deemed sufficiently accurate to merely allow the arms to lift. Hair-line pointers were fitted to the body of the machine, pointing along the weight-arms. The arms were caused to lift until marks scribed upon them came exactly in line with the indicating pointers. By this means it was possible to ensure that the arms reached exactly the same point in every test.

When the weight-arms lifted as described, indicating application of load, the test-strip would be bent to some given extent. The amount of this bend, or deflection, would be indicated on the scale by the pointer actuated by the strip. After noting the reading the load was then removed, whereupon the strip would recover to some degree. The first reading indicates the temporary deflections or set of the strip, while the second reading reveals the permanent set. Loadings were applied and removed continuously in suitable load gradations until such time as either the test-strip reached 1·0 in. of temporary set, or prior fracture.

Many thousands of tests have been carried out by the writer along the lines described, and the method has proved invaluable as a means of comparison when trying out new steels or treatments.

All told, the five steels in question were tested in eight different states of treatment, but it is only proposed to reproduce here results on four of the conditions as being
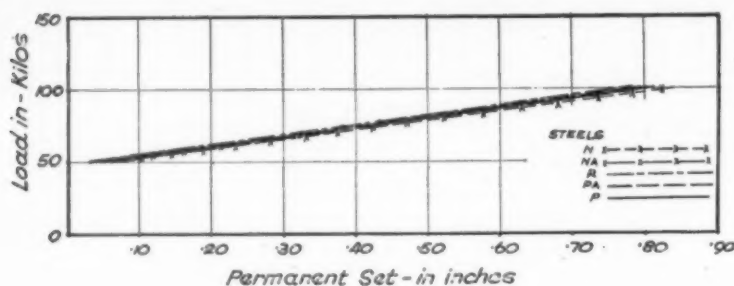
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[*] METALLURGIA January, 1940, p. 73.

Fig. 1.—Normalised series.

Fig. 2.—
Quenched only
series.

sufficient for the purpose. The four in question consisted of normalised, quenched only, and two stages of tempering.

In Tables II to V are given the actual readings obtained in the tests, the permanent set figures being subsequently graphed in Figs. I to IV. For the purpose of abbreviations in the tables, "T.S." indicates Temporary Set, and "P.S." Permanent Set.

TABLE II.
STRIPS IN NORMALISED CONDITION.

Steel reference strip thickness	N. 0·123 in.		NA. 0·123 in.		R. 0·124 in.		PA. 1·23 in.		P. 0·123 in.	
Load Kilos.	T.S. In.	P.S.	T.S. In.	P.S.	T.S. In.	P.S.	T.S. In.	P.S.	T.S. In.	P.S
50	0·18	0·06	0·19	0·07	0·14	0·03	0·16	0·05	0·14	0·03
100	1·0	0·84	1·0	0·81	1·0	0·78	1·0	0·79	1·0	0·80

TABLE III.
STRIPS IN QUENCHED-ONLY CONDITION — 800° C./SALT.

Steel reference Strip thickness	N. 0·123 in.		NA. 0·122 in.		R. 0·123 in.		PA 0·122 in.		P. 0·122 in.	
Load Kilos.	T.S. Ins.	P.S.	T.S. Ins.	P.S.	T.S. Ins.	P.S.	T.S. Ins.	P.S.	T.S. Ins.	P.S.
50	0·12	0·01	0·11	—	0·12	—	0·12	—	0·11	—
100	0·25	0·035	0·24	0·03	0·23	0·015	0·23	0·005	0·23	—
150	0·40	0·07	0·42	0·09	0·37	0·04	0·37	0·03	0·35	0·025
180	0·49	0·105	0·75 Broken		0·44	0·05	0·42 Broken		0·43	0·045
200	0·59	0·15	—		0·51 Broken		—		0·49	0·06
220	0·71	0·21	—		—		—		0·50 Broken	
240	0·78 Broken		—		—		—		—	

TABLE IV.
STRIPS TEMPERED AT 260° C. AFTER SALT QUENCHING FROM 800° C.

Steel reference Strip thickness	N. 0·122 in.		NA. 0·122 in.		R. 0·122 in.		PA. 0·122 in.		P. 0·121 in.	
Load Kilos.	T.S. In.	P.S.	T.S. In.	P.S.	T.S. In.	P.S.	T.S. In.	P.S.	T.S. In.	P.S.
50	0·10	—	0·10	—	0·11	—	0·10	—	0·10	—
100	0·21	—	0·20	—	0·23	0·005	0·20	—	0·21	—
150	0·35	0·04	0·41	0·095	0·36	0·015	0·30	0·01	0·32	0·005
180	0·52	0·14	0·62	0·41	0·44	0·025	0·37	0·015	0·38	0·015
200	0·83	0·37	1·0	0·52	0·50	0·04	0·42	0·02	0·44	0·025
220	1·0	0·55	—		0·55	0·05	0·46	0·025	0·49	0·04
240	—		—		0·61 Broken		0·48 Broken		0·54 Broken	

TABLE V.
STRIPS TEMPERED AT 320° C. AFTER SALT QUENCHING FROM 800° C.

Steel reference strip thickness	N. 0·119 in.		NA. 0·119 in.		R. 0·119 in.		PA. 0·119 in.		P. 0·119 in.	
Load Kilos.	T.S. In.	P.S.	T.S. In.	P.S.	T.S. In.	P.S.	T.S. In.	P.S.	T.S. In.	P.S.
50	0·105	—	0·105	—	0·105	—	0·11	—	0·11	—
100	0·22	—	0·22	—	0·22	—	0·22	—	0·22	—
150	0·52	0·18	0·36	0·035	0·33	0·005	0·36	0·01	0·32	—
180	1·0	0·57	0·48	0·09	0·41	0·01	0·44	0·02	0·39	—
200	—		0·67	0·21	0·46	0·015	0·49	0·03	0·45	0·005
220	—		1·0	0·44	0·51	0·02	0·57	0·045	0·50	0·015
240	—		—		0·58	0·04	0·64	0·07	0·57	0·05
260	—		—		0·65	0·07	0·75	0·12	0·67	0·08
280	—		—		0·71 Broken		1·0	0·27	0·77 Broken	

For those who may be sceptical regarding the quenching temperature of 800° C. employed, it should be explained that 780°–800° C. is standard practice in the production of a certain class of tool, and for the analyses and specifications under review. The range is ample if handled intelligently, and gives rise to a percentage of soft of not more than 0·05% where 100% testing is employed. On the other hand, increased temperatures over the range named merely give rise to slightly increased brittleness, due, presumably, to the increase in grain size corresponding to the increased temperature.

The use of fused salts of the usual alkali group is also standard practice, as where such quenchant is capable of
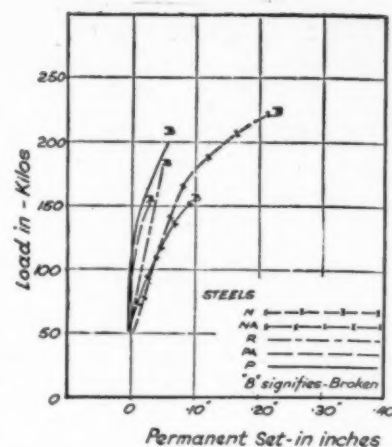
effecting complete hardness penetration it is preferable to oil, as higher impact figures are possible on tempering due to a finer structure of martensitic needles giving rise to a finer network of troostite where rather low tempering temperatures are employed as in these instances. The tempering temperatures were required on the low side in order to yield Brinell hardness readings of 400/500.

Dealing first with the figures in Table II and the corresponding Fig. 1, it will be seen that whereas at a loading of 50 kilogs. the three higher manganese steels each take on a less permanent set than the other two, the actual difference is quite small as to be almost negligible, and at 100 kilogs. all strips take a T.S. of 1·0 in., which invariably implies a state of indefinition, the yield point having been exceeded. Here there is no difference worthy of note attributable to the manganese contents. The graph merely shows a conglomeration of "curves" running straight out to high P.S.

In the quenched condition Table III and Fig. 2, as may be expected, all strips broke during testing before acquiring a T.S. of 1·0 in. This in itself implies that all strips had been thoroughly quenched and none contained soft centres, even in the case of the lower manganese contents. There is, however, the indication of lower efficiency by reason of the fact that the first two exceed a T.S. of 0·70 in. before fracture occurred.

In view of fracture occurring in every instance, the graph, Fig. 2, is not too illuminating beyond the fact that there is becoming now evident a separation of the individual steels roughly in order of their manganese content. In addition, quenching has been the means of providing a very different set of "curves" to those yielded by the normalised state.

In the series tempered at 260° C., low though the latter may be, it is sufficient to remove from the two lower manganese content strips the hardness to an extent where they are capable of taking a temporary set of 1·0 in. without fracture.

The difference between these two steels and the other three in the series is more closely marked in the graph, Fig. 3. The P.S. values of the two in question fall away rapidly to the higher figures of 0·55 in. and 0·52 in., respectively, while the remaining ones all break at a maximum T.S. of 0·61 in., leaving low P.S. values.

Details provided in Table IV show that the two lower manganese strips containing 0·51 and 0·60%, respectively, have failed at a loading of 220 kilos., while the other three still persist. Attention is drawn, however, to the P.S. of steel "R," which is the greatest of the three and which latter is the usual indication of approaching failure, due, it may be presumed, to the manganese being lower than in the other two.

In the final series, tempered at 320° C., three of the strips are insufficiently hard to fracture during test, although, curiously enough, the additional one in comparison

Fig. 3.—Series tempered at 260° C.
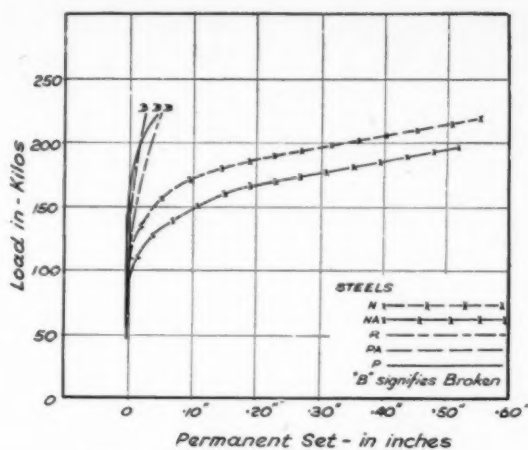
Fig. 4.—Series tempered at 320° c.

with the previous group is the " P.A." with 0·80% manganese, and not the " R " at 0·72% as might have been expected.

The properties as graphed in Fig. 4 are now widely divergent, although a distinct gap continues between the first two, or lower manganese contents, and the remaining three.

Making further comparisons, reference to Table V will show that " N " steel containing 0·51% manganese has failed completely at a loading of only 180 kilos, having a P.S. of 0·57 in., while the same load has been insufficient to cause the slightest permanent distortion in the " P " steel of 0·92% manganese. In the intervening manganese contents at the same loading, P.S. in the case of 0·72% and 0·80%, respectively, is practically negligible.

Summarising the results as a whole, it may be expressed that while it is usual to expect, and possible to obtain, increased tensile strengths with rising manganese contents, the tests as outlined and carried out on strips show no appreciable difference between amounts varying from 0·51–92% when in the normalised condition. On quenching, however, some difference becomes apparent which is more marked with the application of tempering, and while the difference is greatest between the lower two and the higher three, the group as a whole does not show the difference one might expect from a variation of 0·41% manganese from the lowest to the highest content.

The lack of difference expected led to a consideration of the other elements present, and after some little study the following conclusions were drawn :

The sulphur present, having a greater affinity for manganese than iron, unites with the former to form manganese sulphide (MnS), thus absorbing certain of the manganese and preventing its assistance in widening the hysteresis on quenching.

While theoretically the proportion of combination to form the molecule, based on atomic weights, is 1·72–1, it is a reasonably well-known idiom that more like a proportion of 10–1 manganese-sulphur is necessary to nullify the deleterious effects of the red-shortness producing element. In accordance with this practical fact the analyses as quoted in Table I were taken, and ten times the sulphur content was deducted from the manganese present. Of the remaining manganese, if any, one-third was then taken and added to the carbon percentage to yield a nominal figure, which is described as a " hardening value."

As an example of the foregoing, taking steel " NA," 10 times the sulphur content equals 0·45%. Deducted from 0·60% manganese leaves 0·15% of the latter element. One-third of 0·15% equals 0·05%, which added to 0·53% carbon yields a " hardening value " of 0·58%.

By working out the analyses in Table I in this manner, the hardening values show a gross variation of only 0·20% in comparison with 0·41% manganese. This reduced
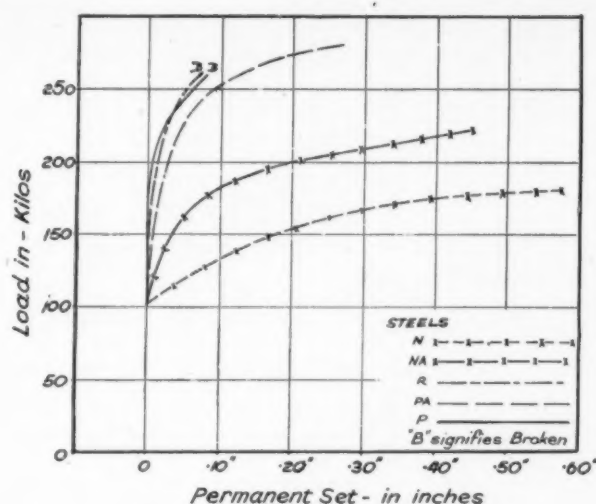
difference is more in keeping with that as obtained in the graphs, and, what is more to the point, bears out hardening practice on carbon-manganese steels. The values of the group examined are included in the table in question.

In conclusion, evidence has been submitted that the properties of carbon steels may vary considerably on heat-treatment according to the manganese content, but in weighing up the potentialities of a given type, the content of other elements require consideration in order to arrive at some standard hardening value along the lines as indicated.

Zinc Smelting and Refining Works in Sweden

IN ordinary times Sweden exports her zinc ore and scrap products of same, the export of scrap alone amounting to some 5,000 tons annually. According to recent information, a domestic electric smelting and refining works has now been established. The new plant, which is installed in buildings of a cyanide works, which was closed down shortly after the end of the Great War, will, to begin with, only deal with zinc ash, cinder and scrap, but it is proposed to recover and refine the zinc ore as well, later on.

New Laboratory for North-West Pacific Area

WITH part of the funds recently appropriated by Congress for the Interior Department, the U.S. Bureau of Mines proposes to build and operate a laboratory within a reasonable distance of the two great Government power plants at Bournville and Grand Coulee Dams. It will be an electro-development laboratory, where Bureau of Mines metallurgists plan to study the recovery and processing of minerals from the Pacific North-West. Improved methods of recovering magnesium and aluminium from the plentiful natural resources of that area, together with research in the processing of tungsten, chromium, manganese, vanadium and other strategic and critical minerals, are to be the chief objectives towards the further development of a vast region long known to be rich in minerals and energy resources.

The new station will be known as the North-West Electro-Development Laboratory, and will be staffed by some 40 or 50 metallurgists and assistants. It will be equipped with electric furnaces and electrolytic cells of various types, ore-crushing and concentrating machinery, chemical laboratory and machine-shop equipment, and other plant needed in experimental and development work.

The Chemical and Physico-Chemical Analysis of Iron and Steel

Twelve Years' Advancement

By E. C. Pigott

Part II. (Contd.)—Papers Describing the Determination of Single Constituents

Nitrogen

Nitrogen is injurious to the properties of steel, especially in causing brittleness. The content of the vast majority of steels and irons ranges from about 0·001 to 0·02%, the surface content of nitrided steels containing considerably more, often over 2%. Only a very small proportion is uncombined, the bulk existing as nitrides of the various constituents. Cunningham and Hamner have shown that the nitrides of Ti, Cb, Ta and V are insoluble in HCl, but may be decomposed by digestion with H_2SO_4, $CuSO_4$ and K_2SO_4. Alternatively, Klinger decomposes alloy steels by vacuo-fusion with alkali peroxide. The rapid colorimetric method of Veinberg is of considerable interest in being a departure from the vacuo and distillation procedures, and with slight modification gives reliable results. This method is best operated as follows :—

A solution of 1 g. of sample in 15 ml. of (1 : 4)H_2SO_4 is diluted to 50 ml. and a cold 5 ml. portion is shaken successively with 5 ml. of water, 4 ml. 25% alcoholic solution of thymol, 8 ml. NaBrO (10 ml. Br_2 + 100 ml. 30% NaOH) and after about 2 mins., with 5 ml. of ether, the solution being cooled to 10° C. between additions. The blue coloration in the ethereal layer is then compared with that obtained from standard steels.

Chipman and Fontana. *Ind. Eng. Chem. Anal. ed.*, 1935, **7**, 391.
(Improvements in vacuo, fusion apparatus.)

Cunningham and Hamner. *Ind. Eng. Chem. Anal. ed.*, 1939, **11**, 303.
(Ti, Cb, Ta and V form insoluble nitrides which are best decomposed by digesting the HCl residue with H_2SO_4, $CuSO_4$ and K_2SO_4.)

Eilender and Diergarten. *Arch. Eisenhüttenw.*, 1931, **4**, 587.
(Small amounts of Al and Mn do not affect the hot extraction method.)

Fer'yanchich. *Zavod. Lab.*, 1932, No. 1, 34 ; *Chem. Zentr.*, 1934, I, 2950.
(A detailed review of methods.)

Getzov. (a) *Chimie et Indust.*, Special No., 1931, 458.

(b) *Zavod. Lab.*, 1935, **4**, 347.
((a) Distillation method, using tin condenser and methyl orange indicator ; high N content causes brittleness.)
((b) In steel, cast iron and ferro-alloys ; a solution of 1 g. in 50 ml. HCl is treated with Zn and 200 ml. 15% NaOH, distilled into 25 ml. 0·1 N H_2SO_4, and the distillate titrated with 0·1 N NaOH.)

Hirano. *J. Soc. Chem. Ind.* (Japan), 44 Suppl. binding, 1941, 32. (In English.)
(In absence of CO_2, bromocresol blue, bromocresol green, methyl red and sodium alizarin sulphonate are all satisfactory indicators.)

Johnson. *Iron Age*, 1934, 134, No. 4, 10–15.
(Allen's titration method ; insoluble residue digested with $HClO_4$ and H_2SO_4.)

Kempf and Abresch. (i) *Arch. Eisenhüttenw.*, 1940, **13**, 419 ; (ii) *ibid.*, 1941, **14**, 255.
(Combined N in carbon and alloy steels ; hot extraction methods considered unreliable ; alkali peroxide fusion satisfactory ; modified H_2SO_4 distillation method recommended.)

Klinger. (a) *Arch. Eisenhüttenw.*, 1931, **5**, 29 ; (b) *Zavod. Lab.*, I, 1933, 20 ; (c) *Arch. Eisenhüttenw.*, 1934, **7**, 551.
((a) Vacuo fusion of 0·1-0·5 g. in 3 g. Na_2O_2 ; absorption of CO_2, O_2, CO, and H_2 and calculation of N_2. Shortcomings of existing methods noted.)
((b) Acid solution methods suitable for Mn and Al steels, but alloy steels containing Cr, Ti, W or V decomposed at 1,000° by vacuo fusion with Na_2O_2.)
((c) Comparison of methods.)

Klinger and Koch. *Arch. Eisenhüttenw.*, 1937, **10**, 463.
(Micro method for nitride surfaces.)

Kovtun. *Zavod. Lab.*, 1937, **6**, 229.
(Indicator consisting of 1·2 g. methyl red and 0·82 g. methylene blue per litre of 90% alcohol.)

Lebedev. *Zavod. Lab.*, 1938, **7**, 1378.
(Improvement in electric furnace and Hg-vacuum pump.)

Lloyd. *Iron and Steel Inst. Special Rep.*, 1935, 236 pp.
(Bibliography 88 refs. and abstracts on influence of N on steel and iron and 22 on estimation.)

Phragmen and Treje. *Jernkontorets Ann.*, 1940, 124, 511–35.
(Largely a critical review ; 82 refs. ; solution in H_2SO_4, with sulphate additions and caustic alkali distillation (the simplest procedure) is quite reliable.)

Portevin and Seferian. *J. Iron and Steel Inst.* Symposium on Welding, 1935, **2**, 483.
(Distillation method. In oxy-acetylene welding, maximum absorption was 0·02% N, but in arc welding, 0·15-0·2%.)

Sloman. *J. Iron Steel Inst.*, 1941, 4–18.
(Vacuum fusion completely reliable for N.)

Sōmiya. *Tetsu-to-Hagane*, 1940, **26**, 43.
(Kjeldahl method ; new apparatus.)

Stevenson. *Indus. Chem.*, 1934, **10**, 307.
(A solution of 1 g. in 20 ml. 1 : 1 HCl distilled with 300 ml. 3% NaOH ; where N <0·02, distillate Nesslerized, otherwise titrated, using methyl red.)

Swinden and Stevenson. *Iron and Steel Inst. Special Report No. 9*, 1935.
(Distillation method ; use of Kjeldahl splash head and 18 in. Liebig condenser.)

Thanheiser and Ploum. *Arch. Eisenhüttenw.*, 1937, **11**, 81 ; *Mitt. K. W. Inst. Eisenfor.*, Düsseldorf, 1937, **19**, 105.
(Review of measuring technique ; modified Orsat app. ; 13 refs.)

Thompson. *Amer. Inst. Mining Met. Eng.*, Inst. Metals Division, Tech. Pub., 1932, 466, 22 pp.
(Occurrence in steel and estimation.)

Vacher and Jordan. *Bur. Stands. J. Res.*, 1931, **7**, 375–99.
(Al and Mn are deposited in cool parts of furnace ; reproducibility is within 0·002% of wt. of sample ; gases extracted by Hg—diffusion pump and passed over CuO, P_2O_5 and Ascarite, the unabsorbed N being measured.)

Veinberg. (i) *Zavod. Lab.*, 1938, **7**, 1251.
(Preliminary paper on colorimetric method based on oxidation of NH_4Cl or $(NH_4)_2SO_4$—formed by dissolving sample in HCl or H_2SO_4—with NaBrO in presence of thymol and extraction with ether.)

Veinberg. (ii) *Zavod. Lab.*, 1940, **9**, 1073.
(In place of ether, iso-Pr ether recommended ; very pure reagents required.)

Veinberg and Proshutinski. *Zavod. Lab.*, 1935, **4**, 390.
(Bibliography (57 refs.), with discussion of proposed methods.)

Wadi and Isii. (i) *Sci. Papers Inst. Phys. Chem. Res.* (Tokyo), 1940, **37**, 65–78.
(Bromocresol blue advocated.)

Wadi and Isii. (ii) *Bull. Inst. Phys. Chem. Research* (Tokyo), 1940, **19**, 491.
(For pig iron, $HClO_4$ was unsuitable, since it contained HNO_3.)

Yasima. *Tetsu-to-Hagane*, 1938, **24**, 947.
(Improvements in vacuum-fusion app. Orsat app. gives greatest accuracy.)

Zeigler. *Trans. Elektrochem. Soc.*, 1932, **62**.
(Improved graphite vacuum fusion method with selective freezing measurements.)

Zolotereva. *Zavod. Lab.* (a) 1938, **7**, 18 ; (b) 1938, **7**, 220.
((a) Extracted gases passed through water ; (b) use of mixed indicator of methylene blue and methyl red in place of Na alizarin sulphonate.)

Non-metallic Inclusions

In general, acid solution methods have been superseded by the more rapid and reliable halogen methods. In America Cunningham and Price's aqueous iodine method is used, and in this country the alcoholic iodine procedure, developed by Rooney and Stapleton ; the latter is inapplicable to alloy steels, since the carbides of tungsten, molybdenum, etc., have melting points higher than those of the oxides and are not decomposed. During extraction, it is inadvisable to have the alcoholic iodine much above 40° C., higher temperatures causing low results.

Colbeck, Craven and Murray have developed the chlorine process, which consists of treatment of the sample at 300° C. with the halogen gas, and is more suitable for alloy steels. In Russia, Fitterer's electrolytic method, employing a dilute $FeSO_4$-NaCl solution, is favoured. Klinger and Koch have devised photoelectric methods for analysis of the residue.

Araki. *Tetsu-to-Hagane*, 1940, **26**, 14–19.
(Use of $KMnO_4$ in 4 HNO_3 to decompose carbides ; previous methods considered unsatisfactory, since carbides retained.)

Colbeck, Craven and Murray. (i) *J. Iron Steel Inst.*, 1936.
(Comparison of chlorine and iodine methods ; SiO_2 and Al_2O_3 unattacked by Cl up to 550° C., but Fe_2O_3 and Mn_3O_4 suffer attack. Iodine method unsuitable for Cr steels, as carbides not decomposed and neither method satisfactory for cast iron.)

Colbeck, Craven and Murray. (ii) *Iron and Steel Inst., Special Report No. 25,* 1939, 109–20.
(Small amounts of Ni, Cu, Mo, V and Ti do not interfere with chlorine method at <800° C., which is, however, unsuitable for graphitic irons as Mn interferes.)

Colbeck, Craven and Murray. (iii) *ibid.,* 173–5.
(Chlorine method is short and simple, compared with iodine method.)

Colbeck, Craven and Murray. (iv) *ibid.,* 177–8.
(Analysis of chlorine residues.)

Colbeck, Craven and Murray. (v) *J. Iron Steel Inst.,* 1941, 38–45.
(Determination of constituent oxides.)

Cunningham and Price. *Ind. Eng. Chem. Anal. ed.,* 1933, **5,** 27.
(Extraction of SiO_2, MnO, FeO, Al_2O_3, with FeI_2–NH_4 citrate solution.)

Daikhes. *Metallurg.,* 1938, No. 12, 151. *Khim. Referat. Zhur.,* 1939, No. 6, 19.
(The chlorine and $HgCl_2$–electrolytic methods are described, the latter being preferred.)

Diergarten. *Metal Progress,* 1937, **32,** 269.
(Description of American technique.)

Duimor. *Zavod. Lab.,* 1932, No. 10, 38–51.
(Fitterer's electrolytical method found superior to others.)

Duvanova and Valdman. *Ural. Met.,* 1937, No. 1, 45 ; *Chem. Zentr.,* 1938, I, 1202.
(Fitterer's method with electrolyte containing 1% NaCl, 3% $FeSO_4$ aq., and 0·3% K tartrate. Residue treated with hot KOH, with $KMnO_4$ in HNO_3, and with 5% KCl.)

Fitterer, *et al. Bureau of Mines Report* 3205, 1933, 70 pp.
(Electrolytic extraction of MnO, MnS, FeS, SiO_2, Al_2O_3 from low carbon steels in 3% $FeSO_4$ aq., and 1% NaCl. If FeO required, acidity raised to avoid contamination by basic $Fe_2(SO_4)_3$ and $Fe(OH)_3$. Sodium citrate serves to separate MnS from MnO, which is soluble.)

Hunter. *Metal Treatment,* 1938, **4,** 177.
(Specimen etched in 10% H_2CrO_4 aq., and inclusions counted ; accurate to ± 5%.)

Kippe and Meyer. *Arch. Eisenhüttenw.,* 1936, **10,** 93.
(Review with 29 refs., in electrolytic method, MgI_2 unsuitable for inclusions containing FeO. By suitably adjusting pH of electrolyte, decomposition of oxides is avoided.)

Klinger and Koch. *Arch. Eisenhüttenw.,* 1938, **11,** 569.
(SiO_2, Al_2O_3, FeO, MnO, FeS, and MnS extracted by means of neutral Na citrate-KBr-KI electrolyte. Residue washed with HCl and KCNS to remove Fe, treated with 60% $HgCl_2$ at 100° C. to dissolve carbide, and then constituents determined photometrically.)

Lukashevich-Duvanova. (a) *Reports Central Inst., Metals Leningrad* No. 16, 1934, 59 ; in English. (b) *Zavod. Lab.,* 1934, **3** ; (c) *ibid.,* 1935, **4,** 499 ; (d) *Metallurg.,* 1936, **11.** No. 5, 19.
((a) Comparison of methods ; bromine or iodine methods take only 4 days and serve for same inclusions as HNO_3 process, which requires 12 days. Fe_3C is not attacked. Electrolytical method gives additional inclusions of $Fe_2O_3.SiO_2$ and magnetic globules of Fe oxides (70%) and MnO (20%). The most detrimental inclusions are Al_2O_3, spinels, Fe oxides, and SiO_2.)
((b) Results from Dickenson's 10% HNO_3–citric acid method, and Fritterer's electrolytic (citric acid) method considered in relation to photomicrographs.
((c) Systematic scheme of analysis.)
((d) Electrolytic decomposition gave negative results.)

Medvedeva and Remin. *Ural. Met.,* 1939, No. 3, 31–6. *Khim. Referat. Zhur.,* 1939, No. 11, 63.
(Treje and Benedicks' process.)

Mikhailova. *Zavod. Lab.,* 1936, **5,** 404.
(25 g. turnings dissolved in 12% H_2SO_4 without heating, 6–7 hours, residue washed free from $FeSO_4$, ignited, weighed, fused with Na_2CO_3 and analysed by Eggerts' method.)

Rooney. *Iron and Steel Inst. Special Report* No. 25, 1939, 141–58.
(In the alcoholic iodine process, 4 methods are available—viz., churning, stirring, boiling, and percolation ; Cu, Cr, Ti, V, and Mo interfere ; results show good agreement with those obtained by vacuum fusion.)

Skapski. *et al. Ann acad. sci. Tech. Varsovie,* 1936, **3,** 219.

Stevenson. *Iron and Steel Inst. Special Report* No. 25, 1939, 179–94.
(Analytical scheme for alcoholic iodine method ; after the separation of SiO_2 cupferron is used to precipitate Fe, Ti, and Zr, the Fe then being determined as sulphide or by means of thioglycollic acid, Ti by means of H_2O_2, or cupferron and Zr as phosphate. The elements Al, Cr, Mn, and P are precipitated, oxine or ammonia being used to separate Al and Cr ; aluminon for estimating Al and diphenyl-carbazide for Cr. For Mn, KIO_4 is used, and P is converted to phosphomolybdenum blue. Both Lovibond and Pulfrich colorimetric technique are described in detail.)

Stevenson and Speight. *J. Iron Steel Inst.,* 1941, 58–64.
(Simplification of alcoholic iodine method ; conditions summarized.)

Scott. *Ind. Eng. Chem. Anal. ed.,* 1932, **4,** 121.
(In simplified apparatus, electrolysis with MgI_2 ; details of analysis.)

Speight. *J. Iron Steel Inst.,* 1941, 77–81.
(Detailed description of analysis of residue obtained in alcoholic iodine method.)

Stevenson. *J. Iron Steel Inst.,* 1941, 76.
(In hydrogen reduction method, refractories give too high a blank at 950° C.)

Swinden, Stevenson and Speight. *J. Iron Steel Inst.,* 1941, 18–26.
(Fractional vacuum fusion ; low results for silicate steels ; high results for rimmed steel.)

Taylor-Austin. (i) *Iron Steel Inst. Special Report* No. 25, 1939, 121–140.
(In modified aqueous iodine method solubility of MnO is still troublesome.)

Taylor-Austin. (ii) *ibid.,* 159–72.
(In the alcoholic iodine method Fe_3P is partially oxidised ; TiC is unattacked.)

Taylor-Austin. (iii) *J. Iron Steel Inst.,* 1941, 64–72.
(Aqueous I_2 method for pig iron ; MnO cannot be estimated, as it is partially decomposed : unsuitable for alloy irons.)

Treje and Benedicks. *Jernkontorets Ann.,* 1932, 116, 166–96.
(Electrolytic apparatus of two compartments separated by diaphragm with sample as anode, 0·1 N K Br + 10% Na citrate, and cathode of Cu sheet in 10% $CuSO_4$. Designed to avoid evolution of H_2 and O_2. Inclusions from Armco iron were 36% Al_2O_3, 62% FeO, and 1·2% MnO ; from Lancashire iron 3·9% Al_2O_3, 93·3% FeO, and 2·8% SiO_2 ; and from Si steels, 40–75% SiO_2 and remainder Al_2O_3.)

Zolotareva. *Zavod. Lab.,* 1937, **6,** 679.
(In Si and Cr steels.)

Oxygen

With most deoxidized steels, the oxygen content ranges from 0·01 to 0·04%, but rimming steels of the Armco type may contain as much as 0·1%. Only a minute proportion exists in the uncombined condition and treatment with aluminium, ferro-manganese, ferro-silicon or ferro-titanium before casting, converts the bulk from FeO into complex oxides of Mn, Si, Al, and Ti. Ferro-silicon leaves the greater part as silicates of Fe and Mn, whilst with aluminium, Al_2O_3 predominates. Entrained oxide particles of slag and refractory materials may also be present.

The hardness of Al_2O_3 causes surface defects during working. Corrosion resistance is seriously impaired by oxygen, notably by silicates in stainless steels. Developments during the period under consideration, have solved many of the difficulties in the various methods. The pronounced segregation renders representative sampling a difficult matter, surface oxygen causing serious errors. Three main types of analytical technique are available, viz :—

(1) Vacuum fusion extraction of the gases with volumetric measurement.

(2) Extraction of the oxides with micro-chemical examination.

(3) Absorption of the water produced on reduction with hydrogen.

None of these has sufficient rapidity and simplicity for routine application. In the vacuum fusion procedure, which consists of heating the sample in a graphite crucible at > 1,600° C. and extracting the oxygen as oxides of carbon, the vapours of the Mn and Al tend to react with the CO, thereby causing low results. Reeve has shown that at 1,600° C., in the presence of tin, even Al-deoxidised steels may be analysed, the temperatures at which reduction occurs being 1,050° C. for FeO, 1,050°–1,150° C. for MnO, 1,300° C. for SiO_2, and 1,350°–1,600° C. for Al_2O_3. Such fractionation gives particularly useful information regarding the state of combination. The accuracy is usually within 0·002% O_2.

Extraction of the oxides may be effected by means of halogens or dilute mineral acid solutions and by electrolytic solution of the metallic material. Eggertz' original iodine method (1868) has undergone considerable modification, notably by Cunningham and Price, Kinzel, Egan and Crafts. Kinzel dissolves the sample in an ice-cold solution of ferrous iodide and ammonium citrate, ignites the residues and estimates SiO_2, MnO, FeO, and Al_2O_3 by conventional methods. In this country the alcoholic iodine method of Rooney and Stapleton is practised, and though unsuitable for stable-carbide steels, the procedure is very sound for carbon steels. Colbeck in this country and Oberhoffer and Wasmuht in Germany have developed the chlorine method, based on the volatility of the chlorides of Fe, Si, Mn, etc., the oxides being non-volatile. Both SiO_2 and Al_2O_3 are unattacked, but low values are obtained from MnO and FeO. Of the acid solution methods, Dickenson's procedure, which consists in extraction with cold 10% HNO_3 and removal of silicic acid by washing with 10% NaOH, gives useful comparative results for well deoxidised steels in which the oxygen exists largely as silicates of Mn and Al. Herty (1930) has applied Kichlines' HCl method and Brown (1933) has found 70% $HClO_4$ a reliable and rapid solvent. Fitterer's electrolytic method of decomposing with a solution containing 3% $FeSO_4$ and 1% NaCl has been modified by Treje and Benedicks, who substituted a bromide solution in order to reduce anodic acidity and inhibited the hydrolysis of iron by means of citrates. The retention of carbides is

troublesome, but the method is satisfactory for SiO_2 and Al_2O_3.

The hydrogen reduction process of Ledebur, in which the resultant water is absorbed and weighed gives useful results on materials rich in FeO, such as Armco iron, but tends to give low results for MnO. Peterson uses a catalyst designed to prevent the loss of CO.

Important bibliographies covering the various methods of determination have been compiled by Peterson (1932) and Elsdon (1935).

Anon. *Ind. Standardization*, 1936, **7**, 262.
(Data from 34 labs. indicates that the vacuum fusion method yields reliable results for plain steels, and the aqueous iodine method is satisfactory for certain deoxidised steels.)

Fardenheuer and Schneider. *Mitt. K. W. Inst. Eisenfor.*, 1931, **13**, 215.

Castro and Portevin. *Rev. Mét.*, 1932, **29**, 414–21; 449–69; 492–506; 553–64.
(Bibliography of 231 titles.)

Chaudron. *Bull. assoc. tech. fonderie*, 1940, **14**, 2.
(Developments in vacuum fusion method.)

Chipman and Fontana. *Ind. Eng. Chem. Anal. ed.*, 1935, **7**, 391.
(By means of an improved vacuum fusion technique, the oxygen of Al_2O_3 in Al deoxidised steels can be quantitatively recovered.)

Colbeck, Craven and Murray. (i) *J. Iron Steel Inst.*, Sept., 1936; (ii) *Iron and Steel Special Report*, 1937, 2016 pp., 124–38; (iii) *J. Iron Steel Inst.*, 1941, 38–45.
(See under "Non-metallic Inclusions.")

Cournot and Halm. *Genie Civil*, 1932, **101**, 7–11, 32–4.
(Application of various methods; oxygen affects the corrosion resistance, the solubility of carbon and ageing.)

Czermak and Eichenthurn. *Arch. Eisenhüttenw.*, 1932, **6**, 145.
(Notes on Ledebur's hydrogen reduction method; as the ratio MnO–FeO increases the reducing power of H_2 increases.)

Diergarten and Piwowarsky. *Arch. Eisenhüttenw.*, 1930, **3**, 627.
(In cast iron, by hot extraction method.)

Egan, et al. *Amer. Inst. Mining and Met. Eng. Pub. No. 498, 1933.*
(Use of FeI_2 reagent; unsuitable for alloy steels containing stable carbides.)

Eilender and Diergarten. *Arch. Eisenhüttenw.*, 1931, **4**, 587.
(Influence of Mn and Al on hot extraction method.)

Elsdon. *Iron and Steel Institute Special Report No. 9, 1925, V.*
(A bibliography of 106 references.)

Ericson and Benedicks. *Jernkontorets Ann.*, 1931, **114**, 549.
(Critical examination of the vacuum fusion method.)

Gerke. *Zavod. Lab.*, 1935, **4**, 1218.
(A critical review of available methods with special reference to the hot extraction process.)

Gray and Sanders. (i) *J. Iron Steel Inst.*, May, 1938.
(The sample (10 g.) is placed between electrolytic Al in a graphite boat and heated at 1,150° C. for 1 hour in hydrogen, the train being of the conventional type. The Al_2O_3 produced is then isolated by means of 1 : 1 HCl and HNO_3.)

Gray and Sanders. (ii) *Iron Steel Inst. Special Report No. 25, 1939, 103.*
(Ni, Cr, Mo, V and Ti do not interfere in Al—reduction method.)

Gray and Sanders. (iii) *J. Iron Steel Inst.*, 1941, 27–31.
(Al reduction method shows good agreement with vacuum fusion, and is suitable for routine control; atmosphere of H_2 replaced by evacuation to 8 mm. Hg.)

Hamilton. *Amer. Inst. Mining Met. Engineers Tech. Pub., No. 540, 1934.*
(Determination in 18 : 8 steel; oxygen may be combined with Cr.)

Hoyt and Scheil. *Amer. Inst. Min. Met. Eng. Tech. Pub., No. 821, 1937.*
(A fractional vacuum fusion method with a discussion of factors that prevent complete extraction.)

Larsen and Brower. *Amer. Inst. Min. Met. Eng.*, 1932.
(Modified Ledebur method; vacuum fusion method may give low values; estimation of diffusible oxygen, which has serious influence on properties.)

Lebedev. (a) *Zavod. Lab.*, 1933, **2**, 917; (b) *ibid*, 1934, **3**, 1078; (c) *ibid.*, 1938, **7**, 1378.
((a) New design of Hg pump and vacuum furnace; (b) vacuum aluminium method in which 20 g. of sample is heated at 1,100° C. with 20 g. Al in a specially designed furnace, the resultant Al_2O_3 being isolated by means of cold HCl; (c) further improvements in Hg pump and furnace.)

Malashenko. *Zavod. Lab.*, 1938, **7**, 83.
(Description of modified Oberhoffer and Keil apparatus for hydrogen reduction method.)

Maurer. *Arch. Eisenhüttenw.*, 1932, **6**, 39.
(In pig iron and cast iron, by the chlorine residue process.)

Meyer. *Arch. Eisenhüttenw.*, 1932, **6**, 193.
(Chlorine residue method found unsuitable owing to attack of oxides.)

Meyer and Castro. *Arch. Eisenhüttenw.*, 1932, **6**, 189.
(Vacuum fusion at very high temperatures.)

Newell. *Iron and Steel Inst. Special Report No. 25, 1939, 97–102.*
(Vacuum fusion in all-steel app. at 1,650° C. and outgassing at 2,100° C. Suitable for routine control; eight estimations in 3 hours.)

Pearce. *J. Iron Steel Inst.*, 1941, 72–6; *Fdy. Trade J.*, 1941, **64**, 317.
(Aqueous I_2 and Al reduction methods show agreement when applied to cast iron. Percentages of constituent oxides are as follows:—

SiO_2	0·003—0·020
FeO	0·009—0·045
MnO	nil —0·002
Al_2O_3	nil —0·008
Total oxides	0·017—0·06
Total oxygen	0·005—0·020

Peterson. *Mitt. Inst. Eisenhüttenw. Tech. Hochschule Aachen*, 1932.
(Critical discussion of hydrogen reduction method with a bibliography of 178 refs.)

Raine and Vickers. *Iron and Steel Inst. Special Report No. 16, 1937.* (a) Pp. 57–61; (b) Pp. 100–107.
((a) Alcoholic iodine and vacuum fusion methods showed good agreement for electric furnace bath samples; (b) vacuum fusion method.)

Reeve. *Amer. Inst. Min. Met. Eng. Contribution 56, 1933.*
(Determination of various oxides by fractionation procedure in Bureau of Standards vacuum fusion method.)

Rooney, Stevenson and Raine. *Iron and Steel Inst. Special Report*, 1937. No. 16, pp. 109–24.
(Alcoholic iodine method.)

Sawamura and Imanisi. (a) *Suiyokwai-Shi*, 1938, **9**, 467; (b) *Tetsu-to-Hagane*, 1938, **24**, 275.
((a) Examination of oxygen segregation in Armco iron using $NiThO_2$ catalyst, total blank does not exceed 0·3 mg.; (b) Sampling technique for the Ledebur method; particles should not exceed 0·1 mm. in diam. Surface oxides removed by preliminary heating at 500° C. for 1¼ hours. Vertical container employed which permits better contact of H_2 with catalyst; suitable only for Armco iron.)

Shishkov. *Zavod. Lab.*, 1933, **4**, 14.
(Hydrogen-reduction and vacuum-heating methods.)

Singer. *Ind. Eng. Chem. Anal. ed.*, 1940, **12**, 127.
(Vacuum fusion at 1,250° C. with Sn; accuracy usually ± 0·001%.)

Sloman. (i) *Iron and Steel Inst.* (a) *Special Report No. 9, 1935*, 71–89; (b) *Special Report No. 16, 1937*, 82–99.
(Detailed examination of the vacuum fusion method.)

Sloman. (ii) *Iron and Steel Inst. Special Report No. 25, 1939, 43–62.*
(Degassing at 2,400° C. All oxides except Al_2O_3 are reduced within 10 mins. at 1,550° C.)

Sloman. (iii) *J. Iron Steel Inst.*, 1941, 4–18.
(Vacuum fusion completely satisfactory for O_2.)

Stevenson. *Ind. Chemist*, 1935, **11**, 235.
(Oxygen exists in steel as oxides of Mn, Si, Al and Ti, as entrapped slag and as occluded CO. Available methods are: (i) Separation of non-metallic inclusions by acid solution; or (ii) by halogens; (iii) H_2-reduction; (iv) vacuum fusion; (v) Al process; 25 references.)

Stevenson and Speight. (i) *Iron and Steel Inst. Special Report No. 16, 1937*, 65–81.
(Vacuum fusion method.)

Stevenson and Speight. (ii) *J. Iron Steel Inst.*, 1941, 32–4.
(Aluminium reduction method.)

Swinden. *Iron and Steel Inst. Special Report No. 16, 1937*, 63–138.

Tawara. (i) *Tetsu-to-Hagane*, 1938, **24**, 541.
(Ledebur's method as modified by Kurokawa found reliable.)

Tawara and Sado. *Tetsu-to-Hagane*, 1940, **26**, 693.
(Rapid modification of Herty's Al_2O_3 method; centrifuged from 7·5 N HNO_3 and ignited residue treated with HF.)

Taylor-Austin. *J. Iron Steel Inst.*, 1941, 34–7.
(Total O_2 in pig iron by Al reduction; high results for Al as adsorption caused by hydrolysis of silicides.)

Thanheiser and Brauns. *Mitt. K.-W. Inst. Eisenfor*, 1935, **17**, 207.
(Description of new high-frequency and carbon-spiral types of vacuum furnace.)

Thanheiser and Ploum. *Arch. Eisenhüttenw.*, 1937, **11**, 81; *Mitt. K. W. Inst. Eisenfor.*, 1937, **19**, 105.
(Hot extraction method with modified Orsat technique.)

Thompson. (a) *Amer. Inst. Mining, and Met. Inst. Tech. Pub., 466, 1932*; (b) *Mining Met.*, 1934, **15**, 215; (c) *Mining Met.*, 1935, **16**, 184.
((b) Progress Report; results of analyses of seven steels by 21 labs.)

Thompson and Holm. (a) *Bur. Stand. J. Res.*, 1938, **21**, 79; (b) *ibid.*, 1938, **21**, 87.
((a) Ledebur method as modified by Brown, Larsen and Schenk gives excellent results for plain Si-deoxidised steels, but is unsuitable for Al-deoxidised steels; (b) Both the vacuum fusion and modified Ledebur methods serve for many alloy steels.)

Thompson, Vacher and Bright. *Amer. Inst. Min. and Met. Eng. Tech. Pub. No. 758, 1936*; *Bur. Stand. J. Res.*, 1937, **18**, 259.
(Analyses by 34 labs. of seven plain carbon steels and one open-hearth steel show vacuum fusion method to be accurate, and aqueous iodine process suitable for Al-deoxidised steels. Description of best procedure.)

Vacher and Jordan. *Bur. Stand. J. Res.*, 1931, **7**, 375–99.

Veinberg. *Zavod. Lab.*, 1936, **5**, 1238.
(A review of American and German practices; 30 refs.)

Veinberg. *Zavod. Lab.*, 1940, **9**, No. 1, 23.
(H_2-reduction method suitable for all steels; 1,250° C. for minimum of 30 mins.; M Pt. lowered by Sb and Sn.)

Veinberg and Beninson. (a) *Zavod. Lab.*, 1935, **4**, 623; (b) *ibid.*, 636.
((a) Discussion of Herty method.)

Veinberg and Miskevich. *Repts. Central Inst. Metals*, Leningrad, No. 17, 1934, 232–6 (in English, 247).
(Hydrogen reduction method; surface absorption of oxygen causes serious errors.)

Vladimorov. *Stal*, 1936, **6**, 1092; *Chem. Zentr.*, 1937, I, 3994.
(Critical study of the Al method with special reference to effects of amount of Al and time of addition.)

Willems. (a) *Arch. Eisenhüttenw.*, 1936, **16**, 193; (b) *ibid.*, 1938, **11**, 627.
((a) Elimination of certain defects in vacuum fusion method; (b) special device to permit recharging during operation in the hot extraction method.)

Yazima. *Tetsu-to-Hagane*, 1938, **24**, 947.
(Vacuum fusion apparatus improved and accuracy increased by using modified Orsat apparatus.)

A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts

*T*HIS report constitutes a summary of data resulting from the metallurgical examination of German and Italian aircraft engine and airframe parts by the Aero Components Sub-Committee of the Technical Advisory Committee to the Special and Alloy Steel Committee formed for this purpose. In this, the third of the series, is presented a summary of the results of investigations on cylinders and cylinder liners, inlet and exhaust valves, and valve springs.

The parts examined represent an extensive range of the various types of enemy aircraft which have fallen into the hands of the R.A.F. since the beginning of the war.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts had been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions due to our blockade on enemy procedure and selection of materials was kept in mind.

Attention was given chiefly to engine parts, but a number of airframe and miscellaneous components were included. Special features concerning design had been noted in certain instances, but these were not the primary object of the investigations.

For the purpose of this report, components of the same type from different aircraft have been considered together and the main features summarised. For fuller details the individual reports should be consulted.

The Sub-Committee responsible for these investigations and for this report comprise Mr. W. H. Dyson, Ministry of Aircraft Production; Dr. H. Sutton, Royal Aircraft Establishment; Dr. R. Genders, Superintendent, Technical Applications Metals, Ministry of Supply; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, The English Steel Corpn., Ltd.; Mr. W. J. Dawson, Messrs. Hadfield, Ltd.; Dr. W. H. Hatfield, F.R.S., Chairman, Brown-Firth Research Laboratories; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Dr. T. Swinden, the United Steel Companies, Ltd.; and Mr. G. Stanfield, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out from the beginning of the war until towards the end of 1941, but investigations have continued and are still in progress, and the work is being carried out meticulously. Naturally, no comparisons are made in the report with corresponding parts in British or American aircraft, neither are certain aspects, which the investigations have shown to be open to criticism, emphasised.

Section V.—Cylinders and Cylinder Liners

*T*HE aero-engine cylinder and cylinder liners examined were classified as follows :—

Liquid Cooled

Report No. 3—Junkers Jumo 211A (see Fig. 1).
  ,, 97—Jumo 211H (see Fig. 2).
  ,, 116—Jumo 211.F.1.
  ,, 125—Jumo 211.F.1.
  ,, 48—Mercedes - Benz D.B. 601A (see Fig. 3).

Air Cooled

Report No. 12—B.M.W. 132K (see Fig. 4).
  ,, 45—Bramo Fafnir 323P.
  ,, 79—Fiat A. 80R.C.41 (see Fig. 5).
  ,, 133—B.M.W. 801A1.

With the exception of the Italian cylinder (Report No. 79) all were of German manufacture.

The machining of the cylinders was good, and the bore surfaces had been finely finished, probably honed; only two of the samples, the Jumo 211A

cylinder (Report No. 3) and the Mercedes-Benz D.B.601A (Report No. 48), showed any pronounced scoring.

The Italian Fiat A. 80R.C.41 cylinder was 0·50 carbon steel, but the German cylinders and liners had been made from a 1½% chromium steel, with the exception of B.M.W. 132K (No. 12), which consisted of a 1% chromium steel with low molybdenum. In all the other steels the presence of molybdenum and nickel appeared to be accidental.

The sulphur and phosphorus contents of the Fiat cylinder were 0·034% and 0·017% respectively, and this steel had evidently been made by the open-hearth

process. The cleanness was only reasonably satisfactory, and a Fox count of 107 was obtained. A micrograph is shown in Fig. 6.

The sulphur and phosphorus contents of the German cylinders and liners ranged from 0·005% to a maximum of 0·031%, but even so it seemed likely that these steels were made in the basic electric furnace. They were classed as clean to reasonably clean, and a typical micrograph is shown in Fig. 7.

Hardness and Tensile Strength

All the cylinders were of uniform hardness with no surface hardening of

TABLE I.—CHEMICAL ANALYSES.

Item No.		C, %.	Ni, %.	Cr, %.	Mo, %.
	LIQUID COOLED.				
3	Jumo 211A	0·44	0·18	1·46	0·08
97	Jumo 211H	0·40	0·05	1·43	0·03
116	Jumo 211.F.1	0·47	0·02	1·49	0·02
125	Jumo 211.F.1	0·49	0·05	1·49	Nil
48	Mercedes-Benz D.B. 601A	0·45	0·09	1·52	Nil
	AIR COOLED.				
12	B.M.W. 132K	0·38	0·27	1·03	0·13
45	Bramo Fafnir 323P	0·45	0·08	1·46	0·03
79	Fiat A. 80R.C.41	0·50	0·19	0·12	Nil
133	B.M.W. 801A1	0·45	0·09	1·50	0·07

Fig. 1.—Junkers Jumo 211A.

Fig. 2.—Junkers Jumo 211H.

Fig. 3.—Mercedes-Benz D.B. 601A.

Method of Manufacture

The macrostructures indicated that the Jumo 211A cylinder (No. 3) and the B.M.W. 132K cylinder (No. 12) had been made as punched forgings but the remainder appeared to have been in the form of tubes.

The Italian Fiat A. 80R.C.41 cylinder had evidently been made from a comparatively large ingot but a small ingot appeared to have been used for the German liners and cylinders.

the bore. Tensile tests were taken from some samples, and from others the equivalent strength was determined from the hardness figures. The B.M.W. 132K cylinder (No. 12) gave a tensile

strength of 67·6 tons per sq. in., with an elongation of 20%, but with this exception, the tensile strengths of all the other cylinders fell within a range of 48—55 tons per sq. in. (See Table II.)

Fig. 4.—B.M.W. 132K.

Fig. 5.—Fiat A. 80R.C.41.
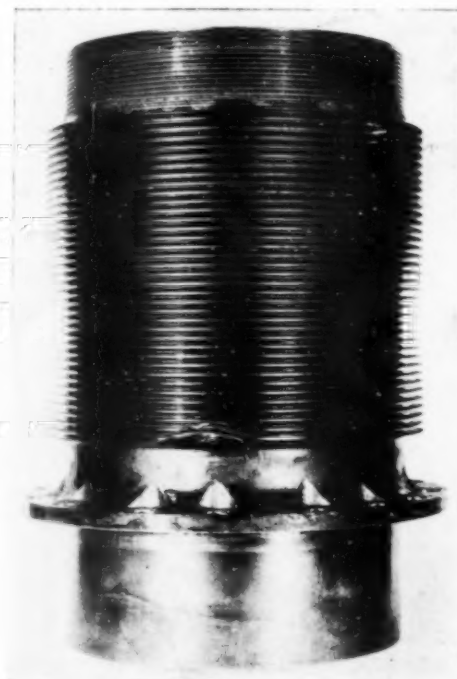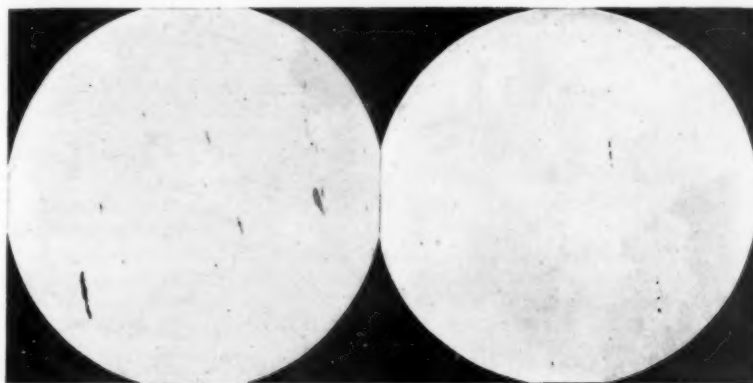
Fig. 6.—Typical micrograph of Fiat cylinder, showing degree of cleanness. x 100.

Fig. 7.—Typical micrograph of German cylinders and liners, showing degree of cleanness. x 100.

Fig. 10.—Method of attaching thermocouple to cylinder shown in Fig. 4. x 2.
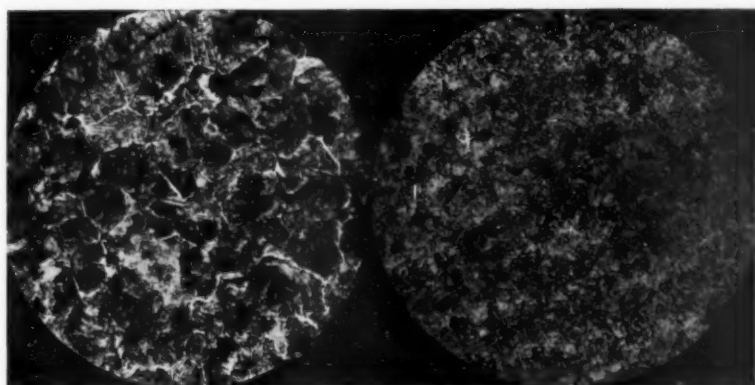
Fig. 8.—Structure of Fiat cylinder. x 100.

Fig. 9.—Sorbitic structure of remaining cylinders. x 100.

No. 3) had been enamelled in black. All the subsequent liners were chromium-plated and this plating had been done on a smooth-ground surface, with no further preparation after plating.

The Jumo 211A liner (Report No. 3, see Fig. 1) had parallel sides, but the sides of all the other liners were tapered (Fig. 2).

The wall thickness of the cylinders and liners was determined as shown below.

The variation in the thickness of the wall of the air-cooled cylinders was an intentional thickening at about one-third of the length below the head.

Heat-Treatment and Microstructure

All the cylinders and liners had been hardened and tempered at normal temperatures producing fine-grained microstructures.

The 0·50% carbon steel Fiat cylinder possessed a microstructure consisting of sorbite grains outlined by a ferrite network (see the micrograph Fig. 8). but the structures of the remaining cylinders were wholly sorbitic. (See Fig. 9.)

			LIQUID COOLED.	Wall Thickness.
Report No.	3	Jumo 211.A		Uniform 0·10 in.
„	97	Jumo 211H		Tapered to 0·08 in, min.
„	116	Jumo 211.F.1		Tapered to 0·1 in, min.
„	125	Jumo 211.F.1		Tapered to, 0·1 in, min.
„	48	Mercedes-Benz D.B. 601A		Uniform 0·10 in.
			AIR COOLED.	
„	12	B.M.W. 132K		Uniform 0·15 in.
„	45	Bramo Fafnir 323P		Uniform 0·10 in.
„	79	Fiat A. 80R.C.41		Variable 0·10 in, to 0·13 in.
„	133	B.M.W. 801A1		Variable 0·12 in, to 0·16 in.

Differences in Design and Manufacture

A comparison of Fig. 1 with Fig. 2 shows that the Jumo liner 211A (Report

TABLE II.

Report No.	Type of Engine.	Component.	Grain Size.	Y.P., Tons/sq. in.	M.S., Tons/sq. in.	El. %.	R./A. %.	Izod, Ft.-lbs.	Diamond Hardness.
3	Junkers Jumo 211A	Cylinder	4—7	—	52·0 approx.	—	—	—	—
		Cylinder bolt	6	60·0	66·7	22·5	66·6	70	—
97	Junkers Jumo 211H	Cylinder liner	6	37·8	47·8	27·5	61·5	—	—
		Liner bolts	—	—	67·1	24·4	63·8	75	324(3 bolts)
116	Junkers Jumo 211.F.1	Cylinder liners : D.B.E. 1	—	—	—	—	—	—	236/240
		S.B.E. 2	—	—	—	—	—	—	260/265
		Cylinder bolts : D.B.E. 1	—	—	—	—	—	—	337
		S.B.E. 2	—	—	—	—	—	—	334
125	Ditto	Cylinder liner	—	—	—	—	—	—	273/279
48	Mercedes-Benz D.B. 601A	Cylinder liner	Mainly 4—6 with a few coarser grains.	46·5	54·2	28·0	—	—	—
12	B.M.W. 132K	Cylinder	5	—	67·6	20·0	50·2	—	—
45	Bramo Fafnir 323P	Cylinder	4—6	—	51·0	22·5	52·2	—	—
79	Fiat A. 80R.C. 41	Cylinder barrel	3—4	—	51·7	26·0	34·3	—	—
133	B.M.W. 801A/1	Cylinder barrel	6—7	45·5	53·7	25·0	33·4	—	—

Fig. 11.—Section showing method of attaching thermocouple to cylinder. x 10.

The depth of the fins of the air-cooled cylinders varied as follows :—

	DEPTH OF FINS.
Report No. 12 B.M.W. 132K	0·45 in.
„ 45 Bramo Fafnir 323P ..	0·72 in.
„ 79 Fiat A. 80R.C.41	0·35 in.
„ 133 B.M.W. 801AI	0·66 in.

The fins on the Fiat cylinder were unusually shallow.

Reference to Fig. 4, a photograph of the cylinder from the B.M.W. 132K engine (No. 12) shows a thermocouple attached to the flange. The two wires consisted of iron and constantan (copper, 54% ; nickel, 42%), and the method of attaching them to the cylinder is shown in Figs. 10 and 11. It was apparent that the wires had been brazed into a small brass plug, which was then put at the bottom of the drilled hole and held in by a copper sleeve.

Cylinder Head Bolts

The cylinder shown in Figs. 1 and 2 were complete with head bolts. Those on the Jumo 211A and 211.F.1 cylinders had been made from 2% nickel, 2% chromium-molybdenum steel, heat-treated to a tensile strength of 66/68 tons per sq. in. ; but the bolts on the Jumo 211H liner (Report No. 97) had been made from a 1% chromium-molybdenum steel, heat-treated to a similar tensile strength, and in this way a considerable economy of alloys had been effected without any sacrifice of mechanical properties.

The threads only of the Jumo 211A bolts, examined under Report No. 3, had been plated, but the Jumo 211H bolts (Report No. 97) had been plated throughout with cadmium, and the Jumo 211.F.1 bolts with chromium.

Section VI.—Inlet and Exhaust Valves

THE following valves were examined :
Two inlet valves and two exhaust valves taken from a Junkers Jumo 211A engine (Report No. 6).

An inlet and two exhaust valves taken from a B.M.W. 132K aero engine (Reports Nos. 15 and 27).

An inlet and an exhaust valve taken from a Mercedes-Benz D.B. 601A aero engine (Report No. 22).

An inlet and an exhaust valve taken from a Bramo Fafnir 323P aero engine (Report No. 46).

An inlet and an exhaust valve taken from a Mercedes-Benz D.B. 601N aero engine (Report No. 89).

An inlet and an exhaust valve taken from a Fiat A. 80R.C.41 aero engine (Report No. 76).

A summary of the essential data is given in Table I.

Chemical Composition

The two inlet valves from the Junkers Jumo engine were made from a high-carbon stainless steel, but all the others had been manufactured from silicon-chromium steel equivalent to British Specification D.T.D. 13B. Without exception the exhaust valves were made from steel to D.T.D. 49B type. All the valves had undoubtedly been made by the basic electric-arc process, and in many instances small titanium and zirconium additions were found. Evidence to the effect that lead-doped fuel had been used was found in the presence of lead in the oxides on all the valve heads. (See Table I.)

Constructional Details

Inlet Valves.—All the inlet valves taken from the Junkers Jumo 211A, the B.M.W. 132K and the Mercedes-Benz D.B. 601N engines were solid, whilst those from the Mercedes-Benz D.B. 601A the Fiat A. 80 R.C.41 and Bramo Fafnir 323P engines were hollow, and had no sodium coolant. On the other hand, all the exhaust valves were hollow, the cavity in some instances running into the head, and all contained sodium coolant. In the solid inlet valves the tappet end was locally hardened, except in the Fiat engine, where Stellite type carbide had been deposited. The hollow stems were sealed by local forging and a hard deposit of Stellite-type carbide. Only in the single instance of the inlet valve from the Bramo Fafnir engine had local forging and hardening been carried out, thus leaving a fine duct which outcropped on to the tappet end of the valve. (Fig. 1, A to F.)

Exhaust Valves.—Greater variation in design was found among the exhaust valves. Exhaust valves from the Junkers Jumo 211A and D.B. 601N engines had been drilled hollow through
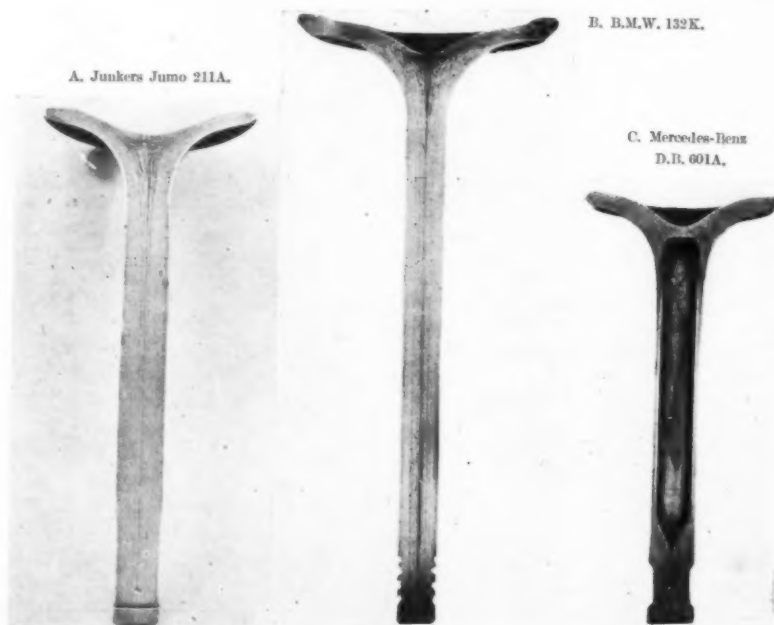
Fig. 1.—Inlet Valves.

TABLE I.—VALVES : CHEMICAL COMPOSITION AND HARDNESS VALUES.

Report No.	Type of Engine.	Type of Valve.	C.	Si.	Mn.	S.	P.
6	Jumo 211A	Inlet 1	1·65	0·19	0·58	0·010	0·020
		„ 2	1·64	0·42	0·14	0·008	0·014
		Exhaust 1	0·42	1·12	1·55	0·027	0·015
		„ 2	0·50	1·45	0·77	0·010	0·016
15	B.M.W. 132K......	Inlet	0·51	2·76	0·35	0·009	0·015
		Exhaust	0·49	1·54	0·55	0·011	0·020
27	B.M.W. 132K......	Exhaust	0·55	1·80	0·71	0·009	0·009
22	Mercedes-Benz D.B. 601A	Inlet	0·45	2·82	0·49	0·016	—
		Exhaust	0·51	1·61	0·63	0·016	0·014
89	Mercedes-Benz D.B. 601N	Inlet	0·37	2·90	0·52	0·027	0·013
		Exhaust	0·46	1·60	0·67	0·008	0·014
46	Bramo Fafnir 323P	Inlet	0·40	2·60	0·34	0·016	0·019
		Exhaust	0·46	1·10	0·85	0·022	0·019
76	Italian Fiat A. 80 R.C. 41	Inlet	0·41	2·58	0·38	0·024	0·028
		Exhaust	0·51	1·00	0·87	0·008	0·019

the head and sealed with a plug of similar material, whilst those from the B.M.W. 132 K engines had been machined hollow in the head and stem and a cap of similar material welded on to the head and a plug of similar material sealed with Stellite-type carbide into the stem at the tappet end. The exhaust valve from the Mercedes-Benz D.B. 601N engine had a drilled hollow stem plugged at the tappet end with steel of similar material and also sealed with Stellite-type carbide. The exhaust valve from the Bramo Fafnir engine was similar except that the head was partially

G. Junkers Jumo 211A.

H. B.M.W. 132K.

I. Mercedes-Benz D.B. 601A.

Fig. 2.—Exhaust Valves.

hollow, this being effected by first drilling the stem and then hot

D. Bramo Fafnir 323P.

E. Mercedes-Benz D.B. 601N.

F. Fiat A. 80R.C.41.

Fig. 1.—Inlet Valves.

upsetting the head. The exhaust valve from the Fiat A. 80R.C.41 aero engine was similar to other hollow-stemmed valves drilled from the tappet end, except that a hollow plug had been inserted towards the lower portion of the stem to prevent too much heat reaching the springs from the sodium coolant. Around the seats of all the exhaust valves Stellite-type carbide metal had been effectively deposited, but no such deposit had been made around the seats of the inlet valves. (Fig. 2, G to L.)

Hardness Tests

The hardness values of all the valves were normal for the structural condition; they were approximately 250/320 V.D.H. for the inlet valves and 220/270 for the exhaust valves. None of the valves had been nitrided.

Macro Structure

The grain flow of the heads of the inlet and exhaust valves was typical of a hot-heading operation. Pronounced structural alteration was noted in the stem of the exhaust valve from the Mercedes-Benz D.B. 601A engine. A high degree of cleanness was noted throughout the examination of these valves.

Micro Structure

All the inlet valves had typically hardened and tempered structures. On the other hand, the general structure of the exhaust valves was austenitic although almost without exception various degrees of a duplex structure were present, the amount of this structure being directly proportional to the measure of cold work put on to the steel towards the end of the forging operation. An effective junction had been made with the base metal wherever Stellite-type material had been deposited.

TABLE I.—VALVES: CHEMICAL COMPOSITION AND HARDNESS VALUES.

Ni.	Cr.	Mo.	V.	Cu.	Al.	W.	Hardness.
0·27	11·7	Nil	Nil	0·05	0·04	Nil	263/336
0·16	12·3	Nil	Nil	—	0·02	0·12	—
13·0	13·0	0·12	Nil	—	0·02	2·81	215/235
13·9	14·5	0·05	Nil	0·06	—	2·38	—
Nil	11·2	<0·05	—	0·09	0·033	Nil	281/306
13·3	15·0	Nil	—	0·043	—	2·38	203/297
13·2	15·5	Nil	Nil	0·08	0·015	2·02	256/274
—	9·07	0·08	—	0·06	—	—	276/289
12·8	13·6	<0·05	—	0·016	—	2·2	249/276
—	10·8	Nil	Nil	0·10	—	—	262/306
13·6	15·4	Nil	0·02	0·08	0·028	2·61	224/243
0·29	11·20	0·04	0·02	0·090	0·022	Nil	254/271
12·90	14·40	0·13	Nil	0·070	—	2·30	223/271
—	8·40	0·16	—	0·046	—	—	360/380
13·8	12·8	0·80	—	—	0·036	2·96	222/254

J. Bramo Fafnir 323P

H. Mercedes-Benz D.B. 601N.

I. Fiat A. 80R.C.41.

Remarks

The inlet and exhaust valves had been made from high-quality steels and showed a high standard of workmanship. They obviously met the design requirements of the engines in which they normally worked. None of the exhaust valves can be directly compared with British aero-engine valves as these are required to work at higher operating temperatures and in the presence of lead-oxide concentrations which necessitate covering the entire head of the valve with an 80 : 20 nickel-chromium alloy. As far as can be judged the enemy exhaust valves compare generally with British exhaust valve practice, whereas the enemy inlet valves are apparently less efficient, probably due to inferior fuel, etc., and would be considered very inadequate by our present standards. No evidence was found to justify the view that shortage of raw materials had influenced alloy content or steel quality.

Fig. 2.—Exhaust Valves.

Section VII.—Valve Springs

THE results of the examination of 34 inner and outer inlet and exhaust valve springs from eight German and Italian aero engines are given in Table I. The table also includes data from Messrs. Brunton's (Musselburgh) Ltd. on eight valve springs from four types of engines. These can be identified by the letters B.M. in the report column. Representative photographs of typical springs are shown in Fig. 1 (Bramo Fafnir 323P, Report No. 18), and Fig. 2 (Mercedes-Benz D.B. 601A, Report No. 18) respectively.

Visual Examination

The surfaces of the springs had been either shot or sand blasted, and showed temper colours. Most of the surfaces had a coating of lacquer, and only in the case of the German B.M.W. (Type 132K) inlet and valve springs was a metallic coating applied, this being of cadmium. Under visual examination none of the springs showed draw marks (see macroexamination).

Dimensions

The dimensions and details of the springs are given in Tables II and III, and a key to the dimensions is shown in Fig. 3. The springs from the two types of Bramo Fafnir engine were conical wound, the remainder being cylindrical.

Analysis

The springs from the Italian Fiat A. 80R.C. 41 engine were made from a 0·50/0·55% carbon, 1% chromium, ¼% vanadium steel, the remainder, with the exception of the Jumo 211.F.1 springs, being of plain 0·60/0·70% carbon steel. It will be noted that these

TABLE I.—VALVE SPRINGS. CHEMICAL COMPOSITION.

| Report No.	Type of Engine.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	V.	Cu.	W
18	German Jumo 211A.											
	Outer..............	0·68	0·125	0·47	0·010	0·025	Trace	0·025	Nil	Nil	Nil	—
	Inner	0·70	0·14	0·53	—	—	Trace	<0·005	Nil	Nil	Nil	—
B.M.1	German Jumo 211D.											
	Outer..............											
	Inner	0·70	0·15	0·58	0·019	0·027	Trace	Trace	Nil	Nil	—	Nil
119	German Jumo 211.F.1.											
	Inlet—Outer	0·61	1·40	0·73	0·030	0·016	0·05	0·70	Nil	Nil	0·09	—
	Inner	0·62	1·47	0·72	0·021	0·016	0·03	0·69	Nil	Nil	0·09	—
	Exhaust—Outer	0·61	1·38	0·73	0·030	0·015	0·04	0·70	Nil	Nil	0·09	—
	Inner	0·62	1·47	0·72	0·022	0·016	0·03	0·70	Nil	Nil	0 09	—
18	German B.M.W. 132K.											
	Inlet—Outer	0·67	0·17	0·48	0·007	0·021	Trace	0·005	Nil	Nil	Nil	—
	Inner	0·63	0·14	0·54	0·007	0·022	Trace	0·015	Nil	Nil	Nil	—
	Exhaust—Outer	0·67	0·145	0·46	0·008	0·022	Trace	0·015	Nil	Nil	Trace	—
	Inner	0·67	0·13	0·50	0·012	0·022	Trace	0·010	Nil	Nil	Nil	—
18	Mercedes-Benz D.B. 601A.											
	Outer..............	0·68	0·17	0·48	0·007	0·022	Trace	<0·005	Nil	Nil	Nil	.
	Inner	0·65	0·17	0·53	—	—	Trace	0·020	Nil	Nil	Nil	—
B.M.2	Mercedes-Benz D.B. 601A.											
	Outer..............	0·70	0·16	0·62	0·024	0·024	Nil	Trace	Nil	Trace	—	Nil
	Inner	—	—	—	—	—	—	—	—	—	—	—
B.M.3	Mercedes-Benz D.B.601N.											
	Outer..............	—	—	—	—	—	—	—	—	—	—	—
	Inner	0·68	0·17	0·72	0·014	0·020	Nil	0·22	Nil	Trace	—	Nil
90	Mercedes-Benz D.B.601N.											
	Inlet—Outer	0·69	0·19	0·60	0·014	0·008	Trace	0·08	Trace	Trace	0·075	—
	Inner	0·67	—	0·54	0·009	0·017	Trace	Trace	Trace	Trace	0·01	—
	Exhaust—Outer	0·65	0·19	0·53	0·011	0·022	Trace	Trace	Trace	Trace	0·01	—
	Inner	0·69	—	0·49	0·016	0·012	Trace	Trace	Trace	Trace	0·05	—
18	German Bramo Fafnir 323P.											
	Outer..............	0·64	0·185	0·54	0·007	0·020	Trace	<0·005	Nil	Nil	Nil	—
	Inner	0·63	0·17	0·49	0·005	0·021	Trace	<0·005	Nil	Nil	Nil	—
B.M.4	German Bramo Fafnir 323P.											
	Outer..............	0·67	0·18	0·72	0·012	0·020	Nil	Trace	Nil	Trace	—	Nil
	Inner	—	—	—	—	—	—	—	—	—	—	—
47	German Bramo Fafnir 323P.											
	Inlet—Outer	0·66	0·20	0·61	0·011	0·023	Trace	Trace	Trace	Trace	Nil	—
	Inner	0·65	0·14	0·50	0·010	0·022	Trace	Trace	Trace	Trace	Nil	—
	Exhaust—Outer	0·65	0·20	0·62	0·012	0·024	Trace	Trace	Trace	Trace	Nil	—
	Inner......	0·65	0·19	0·62	0·011	0·022	Trace	Trace	Trace	Trace	Nil	—
77	Italian Fiat A. 80R.C.41.											
	Inlet—Outer	0·54	0·30	0·64	0·022	0·016	0·09	0·98	Trace	0·25	0·12	—
	Inner	0·50	0·21	0·61	0·012	0·023	0·07	0·94	Trace	0·24	0·12	—
	Exhaust—Outer	0·54	0·22	0·64	0·019	0·017	0·08	0·96	Trace	0·27	0·11	—
	Inner......	0·50	0·22	0·58	0·014	0·023	0·07	0·93	Trace	0·23	0·145	—
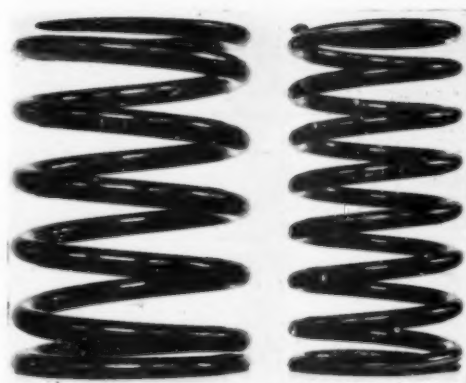
Fig. 2.—Bramo Fafnir 323P.

Jumo 211.F.1 springs are of a silicon-chromium steel, which constitutes a marked departure from previous practice. All are commendably low in sulphur and phosphorus, except the already mentioned Jumo 211.F.1 springs. These have a rather higher sulphur content than the others.

Method of Manufacture of Steel

The analyses of the steels indicate that they are made by the basic electric

Fig. 1.—Mercedes-Benz D.B. 601A.

Fig. 3.—Dimension calculations.

Solid height $\quad = \text{(Total number of coils} - \tfrac{1}{2})d.$
No. of active coils $= \text{Total No. of coils tip to tip} - 1\tfrac{1}{2}$
Length of wire $\quad = D \times \pi \times \text{No. of coils} = D \times \pi \times n$
Total deflection $\quad = \text{Free height} - \text{solid height.}$
Where $d = \text{diameter of wire.}$
$D = \text{Mean diameter of coil at the centre of the spring.}$

are, or possibly the Swedish open-hearth process. The Jumo 211.F.1. springs showed a distinctly higher nitrogen content than the remainder of

the springs, which might be explained by postulating a high nitrogen base (Bessemer scrap) and the absence of a vigorous boil in refining.

Grain Size

The inherent grain size of all the spring steels was coarse, with the one exception of the Jumo 211.F.1 engine, in which the grain size was medium to fine.

Magnetic Etch Test

In none of the springs were any cracks or other defects revealed by magnetic etching.

Macroscopical Examination

Of the springs examined after light etching only those of the Mercedes-Benz D.B. 601A (Report No. 18), and to a lesser extent the Bramo Fafnir 323P (Report No. 47) and the Jumo 211.F.1, showed evidence of draw marks. Otherwise all the springs were free from defects.

Hardness Tests

The hardness of the springs in general varied from 391 to 464 V.P.N., which is equivalent to a range of tensile strength of 81 to 96·5 tons per sq. in. The

HARDNESS VALUES, AND RESULTS OF VISUAL EXAMINATION.

N.2.	Diamond Hardness.	McQuaid/Ehn Grain Size.	Exterior Examination. Coating.	Surface Finish.	Cleanness.
0·004	445	1 to 4 (Mainly 3)	Carbonaceous deposit.	Sand-blasted, bluish temper colour.	Fair.
0·004	391	1 to 3 (Mainly 2)	,,		,,
—	424	—	—	—	Good
—	426				,,
0·016	490	3 to 5 (Mainly 4)	Dark golden-brown lacquer.	Sand-blasted.	Fair.
0·0135	510	3 to 5 (Mainly 4 to 5)	,,	,,	,,
0·0165	495	4 to 6 (Mainly 4 to 5)	,,	,,	,,
0·0125	480	4 to 5	,,	,,	,,
0·0045	421	2 to 4 (Mainly 3)	Bright coating of cadmium.	Finely ground Sand-blasted.	Fair
0·0050	437	,,	,,	,,	,,
0·0045	444	,,	Dull black carbonaceous coating over bright coating of cadmium.	,,	,,
0·0035	444	,,		,,	,,
0·005	455	2 to 4 (Mainly 3)	Dull brownish coating of carbonaceous matter over coating of golden-brown lacquer.	Sand-blasted and marked temper colouring.	Fair.
—	460	1 to 4 (Mainly 3)		,,	,,
—	430	—	—	Light shot-blasted finish, cross-grinding marks.	Good.
—	427	—	—	Shot-blasted finish.	,,
—	434	—	—	Possibly shot-blasted.	Good
—	437	—	—	Probably shot-blasted.	,,
0·006	435	2 to 5 (Mainly 3 to 4)	Dark golden-brown coating of lacquer.	Sand-blasted, marked temper colouring.	Poor
0·005	464	1 to 3	,,	Sand-blasted.	,,
0·006	437	2 to 5 (Mainly 3 to 4)	,,	Sand-blasted.	,,
0·0065	456	1 to 4	,,	Sand-blasted and marked temper colouring	,,
0·0045	435	1 to 4 (Mainly 3)	Green lacquer.	Sand-blasted and showed blue temper colours.	Fair
0·004	451	1 to 3 (Mainly 3)	,,		,,
—	416	—	—	Probably sand-blasted.	Good
—	420	—	—	Shot-blasted.	,,
0·0045	434	1 to 4 (Mainly 2 and 3)	Greenish-brown lacquer.	Sand-blasted and slight temper colouring.	Poor.
0·0045	432	,,	,,	,,	Good.
0·0045	447	,,	,,	,,	Poor.
0·0045	445	,,	,,	,,	Good.
0·009	414	1 to 4 (Mainly 3)	No coating.	Sand-blasted.	Fair.
0·023	406	,,	,,	,,	,,
0·0075	410	1 to 4 (Mainly 3)	,,	,,	Fair.
0·020	409	,,	,,	,,	,,

Fig. 4.—Longitudinal section of Jumo 211A spring. Picric-acid etch. x 300.

Fig. 5.—Longitudinal section of Jumo 211A spring. 2% nitric-acid etch. x 50.

Jumo 211A spring (Report No. 18) and the Fiat A. 80R.C.41 springs (Report No. 77) gave the lowest hardness of the series, and the Mercedes-Benz D.B. 601A springs (Report No. 18) and the D.B. 601N inner springs (Report No. 90) the highest. A departure from this was shown by the more recent engine, Jumo 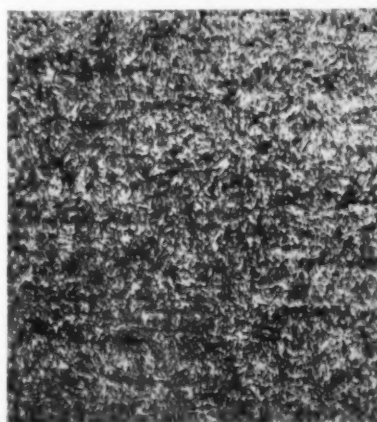211.F.1, which gave hardness values in the region of 490–510 V.P.N., corresponding to a range of tensile strength of approximately 98/105 tons per sq. in.

Microscopical Examination

With the exception of the steels used in the production of the outer and inner springs of the Mercedes-Benz D.B. 601N engine (Report No. 90) and of the outer springs of the Bramo Fafnir 323P engine (Report No. 47), the steels from which the springs were made showed a satisfactory degree of cleanness.

In general, the inclusions consisted of angular and globular silicates and oxides and fine elongated sulphides. The silicates and oxides occurred sometimes in the form of streaks up to 0·030 in. in length.

Structure

All the samples showed a normal hardened and tempered structure which was generally banded (see Figs. 4 and 5). Decarburisation was evident on the outer and inner springs from the Bramo

Fafnir 323P engines (Report Nos. 18 and 47), on the outer springs from Bramo Fafnir 323P engine (Ref. B.M. 4), and on the Jumo 211.F.1 springe (Report No. 119). The remainder were found to be free from decarburisation.

TABLE II.—DIMENSIONS OF OUTER SPRINGS. (Contd. below.)

Report No.	18.	B.M. 1.	119.		18.		18.			B.M. 2.
Type of Engine.	Jumo 211A.	Jumo 211D.	Jumo 211.F.1.		B.M.W. (Type 132K.)		Mercedes-Benz D.B. 601A.			Mercedes-Benz D.B. 601A.
			Inlet.	Exh't.	Inlet.	Exh't.				
Diameter of wire; in. = d	0·183	0·185	0·187	0·186	0·205	0·208	0·154			0·152
Number of coils = n	7½	7	7	7	7	6½	5½			5½
Number of active coils	6	5½	5½	5½	5½	5½	4½			4
Diameter of coils, in.—							Top.	Mid.	Bot.	Top. Bot.
External	1·803	1·75	1·788	1·788	2·136	2·141	1·457	1·554	1·651	1·44 1·63
Internal	1·437	1·38	1·414	1·416	1·726	1·725	1·149	1·246	1·343	1·136 1·326
Mean = D	1·620	1·565	1·601	1·602	1·931	1·933	1·303	1·406	1·497	1·288 1·478
Free height, in. = L	3·047	2·75	2·791	2·787	3·035	2·866	2·055			2·090
Solid height	1·281	1·203	1·215	1·209	1·332	1·300	0·808			0·798
Total deflection	1·766	0·872	1·576	1·578	1·703	1·566	1·247			1·292
Pitch of coils = P	0·549	—	0·547	0·549	0·572	0·552	0·527			—
Length of wire, in.	38·18	34·42	35·2	35·2	42·47	40·99	25·29			25·0
Head of spiral	Right	Right	Right	Right	Right	Right	Right			Right
Weight of springs, oz.	4·27	—	4·00	4·00	5·77	5·70	1·96			—
Stiffness, lb./in.	—	82	—	—	—	—	—			78

TABLE III.—DIMENSIONS OF INNER SPRINGS. (Contd. below.)

Report No.	18.	B.M.1.	119.		18.		18.			B.M.2.
Type of Engine.	Jumo 211A.	Jumo 211D.	Jumo 221.F.1		B.M.W. (Type 132K.)		Mercedes-Benz D.B. 601A.			Mercedes-Benz D.B. 601A.
			Inlet.	Exh't.	Inlet.	Exh't.				
Diameter of wire, in. = d	0·130	0·134	0·135	0·135	0·175	0·178	0·119			0·115
Number of coils = n	10	7½	7½	7½	8½	8½	7½			5½
Number of active coils	8½	6	6½	6½	6½	7	5½			5½
Diameter of coils, in.—							Top.	Mid.	Bot.	Top. Bot.
External	1·282	1·420	1·325	1·322	1·590	1·595	1·117	1·167	1·217	1·090 1·190
Internal	1·022	1·152	1·055	1·062	1·240	1·239	0·881	0·929	0·979	0·860 0·960
Mean = D	1·152	1·286	1·188	1·195	1·415	1·417	0·998	1·048	1·098	0·975 1·075
Free height, in. = L	3·000	2·420	2·558	2·488	2·820	2·754	2·076			2·085
Solid height	1·235	0·938	0·979	0·979	1·356	1·424	0·803			0·776
Total deflection	1·765	1·482	1·579	1·509	1·464	1·330	1·273			1·309
Pitch of coils = P	0·385	—	0·448	0·453	0·398	0·392	0·376			—
Length of wire, in.	36·20	30·3	28·9	29·1	36·69	37·83	23·87			23·3
Head of spiral	Left	Left	Left	Left	Left	Left	Right			Right
Weight of springs, oz.	2·08	—	1·72	1·72	3·75	4·02	1·12			—
Stiffness, lb./in.	—	59	—	—	—	—	—			58

TABLE II. (Contd.)—DIMENSIONS OF OUTER SPRINGS.

Report No.	B.M. 3.	90.							18.	B.M.4.	47.		77.	
Type of Engine.	Mercedes-Benz D.B. 601N.	Mercedes-Benz D.B. 601N.							Bramo Fafnir 323P.	Bramo Fafnir 323P.	Bramo Fafnir 323P.		Italian Fiat A. 80R.C.41.	
		Inlet.			Exhaust.						Inlet.	Exh't.	Inlet.	Exh't.
Diameter of wire, in. = d	0·153	0·154			0·154				0·217	0·216	0·218	0·216	0·207	0·207
Number of coils = n	5½	5½ +			5½				6½	6½	6½	6½	6	6
Number of active coils	4	4½ +			4½				5	5	5	5	4½	4½
Diameter of coils, in.—	Top. Bot.	Top.	Mid.	Bot.	Top.	Mid.	Bot.							
External	1·44 1·63	1·464	1·557	1·650	1·474	1·562	1·650		2·115	2·095	2·120	2·107	2·175	2·175
Internal	1·154 1·324	1·156	1·249	1·342	1·166	1·254	1·342		1·681	1·663	1·681	1·675	1·761	1·761
Mean = D	1·287 1·477	1·310	1·403	1·496	1·320	1·408	1·496		1·898	1·902	1·891	1·891	1·968	1·968
Free height, in. = L	2·000	2·012			2·038				2·937	2·940	2·940	2·901	2·420	2·435
Solid height	0·803	0·808			0·808				1·302	1·296	1·308	1·296	1·138	1·138
Total deflection	1·197	1·204			1·230				1·635	1·644	1·632	1·695	1·282	1·297
Pitch of coils = P	—	0·462			0·514				0·579	—	0·594	0·599	0·563	0·543
Length of wire, in.	24·97	25·34			25·44				38·76	38·37	38·84	38·62	37·11	37·11
Head of spiral	Right	Right			Right				Left	Left	Left	Left	Right	Right
Weight of springs, oz.	—	2·07			1·96				6·09	—	6·09	6·09	5·24	5·24
Stiffness, lb./in.	80	—			—				—	108	—	—	—	—

TABLE III. (Contd.)—DIMENSIONS OF INNER SPRINGS.

Report No.	B.M. 3.	90.							18.	B.M.4.	47.		77.	
Type of Engine.	Mercedes-Benz D.B. 601N.	Mercedes-Benz D.B. 601N.							Bramo Fafnir 323P.	Bramo Fafnir 323P.	Bramo Fafnir 323P.		Italian Fiat A. 80R.C.41.	
		Inlet.			Exhaust.						Inlet.	Exh't.	Inlet.	Exh't.
Diameter of wire, in. = d	0·1175	0·119			0·119				0·165	0·1665	0·166	0·166	0·166	0·166
Number of coils = n	7½	7½			7½				8½	8½	8½	8½	7	7
Number of active coils	6	5½			5½				7	6½	7	7	5½	5½
Diameter of coils, in.—	Top. Bot.	Top.	Mid.	Bot.	Top.	Mid.	Bot.							
External	1·09 1·19	1·114	1·164	1·215	1·117	1·168	1·220		1·529	1·470	1·533	1·533	1·610	1·610
Internal	0·855 0·955	0·876	0·926	0·977	0·879	0·930	0·982		1·199	1·137	1·201	1·201	1·278	1·278
Mean = D	0·9725 1·0725	0·995	1·045	1·096	0·998	1·049	1·101		1·364	1·3035	1·367	1·367	1·444	1·444
Free height, in. = L	2·030	2·044			2·025				2·933	2·940	2·888	2·994	2·220	2·220
Solid height	0·793	0·803			0·803				1·320	1·332	1·328	1·328	1·079	1·079
Total deflection	1·237	1·241			1·222				1·613	1·608	1·560	1·576	1·141	1·141
Pitch of coils = P	—	0·371			0·369				0·398	—	0·407	0·410	0·421	0·422
Length of wire, in.	23·3	23·80			23·90				36·42	34·80	36·51	36·51	31·75	31·75
Head of spiral	Right	Right			Right				Right	Right	Right	Right	Left	Left
Weight of springs, oz.	—	1·17			1·17				3·39	—	3·39	3·39	2·87	2·87
Stiffness, lb./in.	56	—			—				—	59	—	—	—	—

The Basic Open-Hearth Process To-Day

Part III.—Melting Practice (Continued)

By W. Geary

In this part of the series the author reviews charging practice, and briefly discusses variations in hot metal and cold, fixed and tilting furnaces, and considers deoxidation practice, slag control, control of additions, rimming steel, control of grain size, low alloy steels, lead-bearing steels, and the Perrin process. Attention is directed to the control of quality of steel in the basic open-hearth furnace.

Charging Practice

I. Fixed Furnaces.—To get the raw materials into the furnace with correct timing and in proper sequence is one of the open-hearth operator's principal tasks, for the subsequent operations can be greatly influenced for good or ill by the charging technique. In cold-metal practice, when heavy scrap is available, constant care must be exercised to avoid a charge being put in too quickly for the thermal capacity of the furnace. J. Gibson[1] describes how scrap was packed into charging boxes, increasing the weight per box threefold, with a resulting decrease of 1 hour in charging time ; unfortunately, nearly an hour was lost in the melting time, which made the cost of scrap preparation almost a dead loss. Too slow charging, however, can result in a two-fold delay. First, a simple loss of time ; secondly, if there is undue delay between the charging of successive runs of scrap, liquid may be formed which will be set back by subsequent additions. Charges that have been set back are always difficult to remelt. Summarising the above considerations, we can say that cold-metal furnaces must be charged at a certain rate to establish a balance between the heat requirements of the ingoing materials and the thermal capacity of the furnace.

Furnaces working the hot-metal process, due to the large amount of heat brought to the system by the molten iron, are not so sensitive to accurate timing of charging operations. It is of course a question of degree ; if a large proportion of scrap is being used careful heating is needed, but where a large proportion of hot metal is used it is generally advisable to charge the furnace just as quickly as the machinery can do it. Although for every plant, perhaps for every furnace, an optimum charging time must be worked out, the author's experience with hot-metal practice is that time is often lost with slow charging, but very seldom lost due to a charge being put in too quickly.

The charging sequence in both cold- and hot-metal practice must be designed to give as quick a melt as possible, together with the quickest possible formation of a suitable slag. A number of factors are involved—e.g., whether the lime or limestone should be low in the charge or high ; whether in low-scrap hot-metal practice the scrap should be on the bottom of the furnace or on the top of the charge. Space does not permit full discussion of these problems. The interested reader is recommended to study the Symposium on Steelmaking, where he will find abundant information on the subject.

II. Tilting Furnaces.—The operation of the Talbot process, in which only about a quarter of the finished steel is tapped, is not now customary. The usual practice with tilting furnaces is to tap the greater proportion of the finished steel, leaving in the furnace only a small amount of molten steel and the tapping slag. The materials for the following charge are then added just as in charging a hot-metal fixed furnace.

Oxidation

The open-hearth furnace, regarded as a piece of chemical plant, is essentially an oxidising apparatus. A good deal of loose thinking has existed among operating personnel in the past, based on the idea that the furnace may be worked at will as an oxidising or a reducing apparatus. The true situation is that oxidation can be subjected to a certain amount of control, but cannot be stopped. To use a gas flame that would establish a reducing influence on the slag surface would decrease the flame temperature to below that necessary for the continuance of the melting process. B. M. Larsen[2] shows that with complete combustion there is a ratio of oxygen pressures of around 10 to 100 million between gas and metal, and therefore a continuous flow of oxygen from furnace gases through the slag to the metal. The basis of open-hearth operation is the control of this oxidising process ; it may be speeded up or slowed down, but it goes on. Dr. A. McCance, in his masterly exposition of the physical chemistry of steelmaking,[3] points out that the equilibrium constant—

$$C \times FeO = \text{constant}$$

is of fundamental importance in steelmaking.

I. Oxidation by Furnace Atmosphere.—Oxidation by the furnace atmosphere starts as soon as the charging starts, and continues until the heat is tapped. The dominating factor in controlling the amount of oxidation performed by the furnace atmosphere is time. A slow-working furnace will do more oxidising than a fast one. This occurs in spite of the fact that a fast-working furnace frequently operates during the charging and melting periods with a short flame carrying excess air ; the greater thermal input reduces the time during which the charge is subjected to the effect of the furnace atmosphere. Certain minor factors also have to be taken into account : more oxide will be formed on a given weight of scrap when it is thin and light and so exposes increased surface to the flame. A principal object in charging is therefore to charge as quickly as permitted by the thermal capacity of the furnace, so that the charge may be covered by slag at the earliest possible moment. Once the slag cover is formed, oxidation of the charge proceeds by means of a cyclic reaction. Oxygen in the furnace atmosphere converts a portion of the FeO in the slag to Fe_2O_3, which is reduced to FeO when it comes in contact with the liquid steel surface. In this way oxygen is carried from the furnace atmosphere, through the slag, to the metal. The rate of transfer depends on the fluidity of the slag and upon the degree of agitation that is available to assist diffusion.

II. Oxidation by Additions.—In normal melting practice the amount of oxidation done by the furnace atmosphere is insufficient to maintain the desirable speed of carbon removal during the early part of the refining period. The reaction is therefore stimulated by the addition of oxide in solid form. Ore or scale is used. Where phosphorus is high scale tends to oxidise this element in preference to carbon. Ore is, therefore, the usual medium for removing carbon. In amount, oxide feeds must be related to the inherent oxidising rate of the furnace—i.e., a fast-working furnace may be more quickly and heavily fed with oxide than a slow-working one. Provided a satisfactory slag has been

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1 Symposium on Steelmaking. Iron and Steel Institute, Special Report No. 22, p. 477.

2 B. M. Larsen, *Metals Technology*, 1941. "Controlling Reactions in the Open-Hearth Process," p. 8.

3 Symposium on Steelmaking. Iron and Steel Institute, Special Report No. 22, p. 337.

formed, carbon removal is usually done as quickly as possible in the early stages of working. When the desired carbon content is being approached, the rate of removal is commonly slowed to about 0·20% per hour. Ore additions are discontinued in the late refining period, the carbon reduction being effected by furnace atmosphere, helped by scale additions to the slag.

It is not nowadays generally considered that the oxygen content of the bath corresponds to equilibrium in the partition of the oxides between metal and slag. In the metal phase the C–FeO reaction proceeds steadily in a bath which is boiling freely, and a condition of near-equilibrium is maintained. The normal slag has an excess of FeO, forming as it were a " head " which supplies oxygen to the reaction zone under the influence of the stirring action of the boil. Fig. 1, taken from Larsen's paper,[3] is interesting in this connection.
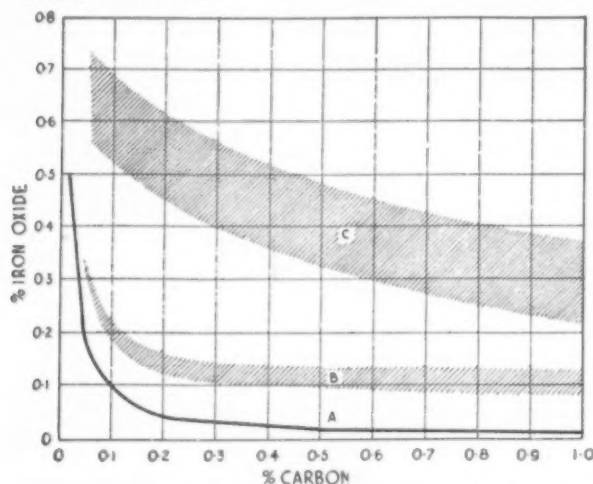

Fig. 1.—Curve A, C–FeO equilibrium at one atmosphere pressure. Zone B, observed C and FeO values in steel bath. Zone C, approximate (FeO) contents required for equilibrium with actual slags.

The estimation of oxygen in steel has been the subject of extensive experimental work. In this country most of the work has been done under the direction of Dr. Swinden, the chairman of the Oxygen Sub-Committee of the Committee on the Heterogeneity of Steel Ingots, while in America much valuable work has been done by Herty and his collaborators. It is expected that analytical technique will develop until the oxygen content of a steel bath may be estimated in a stage laboratory during the working of a heat.[4]

Slag Control

Conventional Practice.—From the earliest days of the basic open-hearth process, slag control has been exercised by the melters. There is much truth in the adage, " Get the slag right and the metal will look after itself." The usual practice at the present time is to put in with the charge such quantity of lime or limestone as experience dictates, and, where charge ore is used, an amount judged sufficient to leave a suitable melt-out carbon. The judgment of the quantities of both limestone and ore are based on such knowledge as is available of the composition of the charge, particular regard being paid to the amount of acid-forming elements present. From the time the whole of the charge is in the furnace, the control of the slag, in conventional practice, is solely in the hands of the melter. Where regularity of steelmaking materials exists in a given shop, it is possible to obtain, in a good proportion of the heats, melting slags of reasonably constant composition. Nevertheless, even when a shop is operating under good conditions, variations will occur. There is always a desire to shorten the melting time by not charging an excess of limestone,

while comparatively small variations in the silicon content of the iron cause noticeable variations in the basicity of the slags. Towards the end of the melting period it becomes possible to form a judgment of the type of slag that has formed, and to make an approximation of its composition. The melter has at his disposal a number of indicators. Invariably, the first judgment is made by the appearance of the slag in the furnace. Slags resulting from a charge too high in silicon are thin and watery and look like a dark lake on which float lumps of lime that appear never to dissolve. It is now known that the reason these lumps resist solution is that they are coated with a refractory layer of dicalcium silicate that can only be fluxed by high concentrations of iron oxide or fluor spar. If the charge is too low in silicon the slag will be thick with lime, with only small amounts of fluid slag apparent. These slags are readily made workable by " opening-out " with scale or fluor spar.

Upon the melter's judgment, therefore, depends the amount and the kind of addition that is made. Most melters now know that the first essential in good practice is to make a really fluid basic slag as early as possible. This was not generally realised until comparatively recent times ; too often in the past, when the melting carbon was high, oxide would be fed and the next sample would show a reduction in carbon, but no reduction in phosphorus. Lime, spar, and probably scale would then be fed and further samples taken. Such charges usually ended in the elimination of the carbon while the phosphorus was still high, and, further, it was seldom found that the sulphur had been appreciably reduced. These charges undoubtedly caused anxiety to the melter ; he was making almost continuous additions to the slag, which never had a chance to become really fluid and active.

The importance of early and complete slag-formation was stressed by R. Percival Smith,[5] who pointed out that patience during this period would be amply rewarded, in that the bath could then be boldly fed and the sulphur and phosphorus would quickly drop to a low figure, the slag opening out to an even boil.

During the working process, then, be it badly or well managed, the melter has the slag under continual observation. In addition to his inspection of the slag in the furnace, he uses as an indicator the appearance of the cooled slag on a rod. The thickness of the coating gives a measure of the fluidity of the slag, and the colour and texture of the coating an indication of its composition. The melter even uses his ears—he likes to hear a crackling sound as the slag cools on the rod. He sums up, by his experience, the evidence of the various indications and decides what additions are necessary.

Other aids to the melter are of comparatively recent origin. One method is the use of slag cakes. Slag is poured into standard moulds, and from characteristic markings and structure of the top and bottom surfaces and the fracture of the cake, it is possible to estimate fairly accurately the lime-silica ratio of the slag. The analysis of the slag for iron has long been a standard aid to the melter, but in itself is not sufficient guide when an attempt is made to establish control methods.

Slag Control in Practice.—It will be clear from the foregoing remarks that the conventional melting practice is definitely not under scientific control. The best practice, in the hands of the most competent melter, must be regarded as rule of thumb. It is impossible under such conditions to avoid irregularity in tap-to-tap times and in steel quality, or to avoid waste of lime, iron, fuel, etc. The possibility of bringing a measure of control to bear is therefore most attractive, and particularly now that steel specifications are becoming increasingly rigorous and the need for economy being ever urgent, open-hearth operators are giving more and more attention to it.

The common method of controlling the composition of a

4 Discussion on Eighth Report on the Heterogeneity of Steel Ingots. *Journal of the Iron and Steel Institute,* 1939, No. 1, p. 599 P *et seq.*

5 Symposium on Steelmaking. Iron and Steel Institute, Special Report No. 22, pp. 224–225.

slag to a desired end is to control the lime-silica ratio. For standard conditions in a given shop such ratio gives a relative measure of the basicity of the slag, but because other constituents of the slag affect the true basicity, the control ratio is determined by empirical means. Actually, very little is known about the true basicity of slags : for example, it is not yet known how much active lime there is in an open-hearth slag.

The practical application of the control is operated in two main stages. These will be considered in the order in which they present themselves.

Control of Charge.—Slag control in the open-hearth furnace begins in the blast furnace. Unless the raw materials for steelmaking are reasonably regular in composition and quality no great success can be made of any control method. Herty,[6] discussing slag control, expressed the view that the silicon content of the hot metal was the primary cause of the variations in the working of open-hearth heats. Table I is taken from his paper, and illustrates the effect of silicon variation on the lime-silica ratio in a given charge. Supposing the steel to be made requires a lime-silica ratio of 3·5, lime additions would be needed during the working of the heat to the extent shown in Table II.

TABLE I.
RELATION BETWEEN SILICON IN HOT METAL AND SLAG ANALYSIS

Silicon in Hot Metal, %.	Final Slag Analysis, %.		
	SiO₂.	CaO.	Ratio CaO/SiO₂.
0·6	10·3	48·7	4·7
0·8	12·0	47·7	4·0
1·0	13·7	46·8	3·4
1·2	15·3	45·9	3·0
1·4	16·8	45·1	2·7
1·6	18·3	44·3	2·4
1·8	19·7	43·6	2·2
2·0	21·1	42·8	2·0

TABLE II.
RELATION BETWEEN SILICON IN HOT METAL AND LIME REQUIRED FOR CORRECTION.

Silicon in Hot Metal, %.	Burnt Lime Required to Give a Lime-silica Ratio of 3·5.	Silicon in Hot Metal, %.	Burnt Lime Required to Give a Lime-Silica Ratio of 3·5.
	Lb.		Lb.
0·6	None	1·4	4,800
0·8	None	1·6	7,000
1·0	300	1·8	9,200
1·2	2,500	2·0	11,400

The addition of the calculated amount of lime will restore the proper ratio, but the heavy feeds inevitably delay production. It is therefore important to aim for charging conditions that will give as nearly as possible a standard melt.

Control of Additions.—When a charge is melted, the first thing that is needed is knowledge of the composition of the slag. Mention has been made of some of the methods by which this may be estimated, but by far the best way is to obtain accurate knowledge by means of chemical analysis.

Until recently methods of analysis were too slow for purposes of control, but as a result of painstaking work it is now possible to determine the SiO₂ and P₂O₅ content of the slag within 30 to 35 mins. of receiving the sample. This result was achieved in the stage laboratories of the Templeborough melting shop, and the author is indebted to Mr. G. A. V. Russell and Messrs. Steel, Peech and Tozer for permission to comment on it. The half-hour thus used for analysis could not be spared from the melting time, and so it was decided to try to anticipate the sampling. It was established that the composition of the slag about half an hour before melting differed only slightly from that at the melt. This is shown in Table III :—

TABLE III.
SAMPLES OF SLAG TAKEN BEFORE CLEAR MELTED.

—	SiO₂.	Fe.	CaO.	P₂O₅.	MnO.
Before melted ...10.50 a.m.	18·0	2·6	54·6	8·13	4·70
"　　"　...11.20 a.m.	17·6	2·5	53·76	8·22	4·96
Melted ....11.35 a.m.	17·2	3·4	53·34	8·18	5·03

6 C. H. Herty, Jnr. *Metals Technology*, 1940, June.

Steel samples were analysed for carbon and phosphorus, and the weight of lime charged being known, as well as the Fe, SiO₂ and P₂O₅ content of the slag, it thus became possible to know within a few minutes of a charge being melted what corrective additions were needed. The practice is to add all the necessary lime and when this has been slagged all the oxide feed. The determination of this amount was the subject of another series of experiments, but it is now successfully operated according to the following formula :—

$$0·78 \ (C + P) + 0·24S \ (T - M) - 13R = X$$

where C = carbon to be removed (in units of 0·01%), P = phosphorus to be removed (in units of 0·01%), S = slag weight (tons), T = iron content of slag at tapping (%) (anticipated), M = iron content of slag at melting (%) (observed), R = refining time (hours), X = oxide required (cwt.).

An example of the operation of the system is shown in Table IV.

TABLE IV.
SLAG CONTROL.

Old Method.			C.	Time.	C.	New Method.		
Lime.	Spar.	Oxide.				Lime.	Spar.	Oxide.
2 12 0		....	0·77	0	0·97	1 19 0		
						1 6 0		
	0 10 0	....	0·70	½		.....	0 10 0	
				¾		....		5 13 0
		2 12 0 ..		1				
				1¼				
0 13 0		....	0·46	1½	0·41			
				1¾				
				2	0·35			
			0·38	2¼	0·20			
			0·32	3				
				3¼	0·13	.... Tapped		
0 13 0		0 10 0 ..	0·30	3½				
			0·20	3¾				
			0·17	4				
	Tapped			4¼				

Slag control is nobody's secret. But to say that the principles of slag control are known is not to say that one man's method can be used in another man's shop. A system of control can be applied in another shop only by adapting the detail of the practice to the conditions existing in that shop. Slag control to a certain degree is of course used by all operators, but any operator who desires to establish a fuller control will find it necessary to take into consideration the local conditions peculiar to his plant. For example, a particularly awkward problem is presented to those whose practice necessitates a flush-off of melting slag. The loss of this slag makes it necessary to apply control rather from the analysis of the metal than from the analysis of the slag, and this is being successfully done in a number of shops.

Deoxidation Practice and Cleanliness

Deoxidation of steel is really a misnomer. What actually happens is that the form in which the oxygen exists is changed. The addition of the usual deoxidisers—silicon, manganese and aluminium—converts the dangerous FeO to oxides whose presence in reasonable amounts does not impair the quality of the steel. The first requisite for good deoxidation practice is good melting practice. The transfer of oxygen to the steel is encouraged while the carbon is high, but is slowed down as the end point approaches. For most special grades of steel no feed ore is added for about 2 hours before tapping, and towards the end of the refining period the slag is thickened with lime to reduce the rate of transfer of oxygen. It is not possible to stop this transfer completely, as has been shown, and in normal working the oxidising power of a slag increases with its basicity.[7] Also, it is important to maintain the boil until the desired end is reached, and the boil, although maintaining the amount of FeO in the steel at near-equilibrium, tends to encourage

7 P. M. Ivanov and G. A. Romodin. *Archiv für as Eisenhüttenwesen*, 1936, Vol. 10, Dec., pp. 229–232.

oxide transfer from the slag. In good practice, however, the rate of oxygen transfer and carbon removal can be greatly slowed down. Heats of steel that are to be fully killed are usually " blocked " with Spiegeleisen or silico-spiegel. Spiegel may be used in a series of " runs," the bath being allowed to reboil after each. The final addition of silicon and manganese may be made in either the ladle or the furnace. Usually in this country silicon is not added in the furnace except in the form of silico-manganese. Ferro-manganese is fairly often added in the furnace, leaving the ferro-silicon to be added in the ladle. The use of silico-manganese is good practice ; the inclusions formed from this alloy are of a type that readily assume a comparatively harmless form, even if they do not remove themselves completely from the steel. To attain the killed condition in which the steel will solidify quietly without the evolution of gases, it is often necessary to add aluminium. This addition may be made in the furnace, the ladle, or the moulds. American practice seems to favour the addition in the ladle, where the amount varies from 0·25 lb. to 0·90 lb. Al per ton of steel. This addition is rather more than is usual in this country, and may to some extent account for the generally larger teeming nozzles used in America.

When making partly killed steels some gas is allowed to remain in the steel, to be evolved late in the solidification of the ingot. The amount will depend upon the purpose for which the steel is intended. Less time need be taken by the deoxidation process in the furnace, but no less care should be taken in the refining process. A lesser quantity of deoxidiser is used, frequently the required degree of deoxidation being established by a final addition of aluminium in the moulds.

The cleanliness of a steel, or its freedom from inclusions, depends on a number of factors. The production of clean steel is naturally facilitated by the maintenance of a high standard of general cleanliness in the casting pit equipment : moulds must be scrupulously clean, while landers and ladles must be not only free from dirt, but must be provided with suitable refractory materials. Inclusions are also formed by the products of deoxidation, and the greatest aid to their minimisation is proper deoxidation practice. The desirable condition is low oxide content of the bath to start with, and the use of deoxidising agents that will form inclusions of a type that have a chance to free themselves from the steel. Inclusions observed in a sample of steel may be checked against a standard chart. A typical example of such a chart is published by G. W. Walker.[8]

Rimming Steel.—The manufacture of rimming steel has during recent years been brought much more closely under control than was formerly the case. Rimming steel has been satisfactorily made on a commercial scale for a long time, but until comparatively recent years many operators were ploughing a lonely furrow. The publication of results of research in the various reports of the Committee on the Heterogeneity of Steel Ingots and the collection of operating data in the Ninth Report,[9] has enabled an individual steelmaker to check his practice against both scientific thought and the practices followed by other operators.

The first requirement for successful rimming steel manufacture is regularity in the quality and composition of the steelmaking materials. When a rimming heat is being made there is, as it were, a comparatively narrow channel along which the furnace practice must go. If the bath at melting has either too much or too little carbon, rimming steel will not be safely and successfully made. A hard melt, needing heavy oxide feed, can be shaped up fairly well, but the finishing technique that is applied to the normal heat will not suffice, and there is always some risk of abnormality in the behaviour of the steel in the moulds. In the case of a soft melt, one in which there is less than 0·20% of carbon
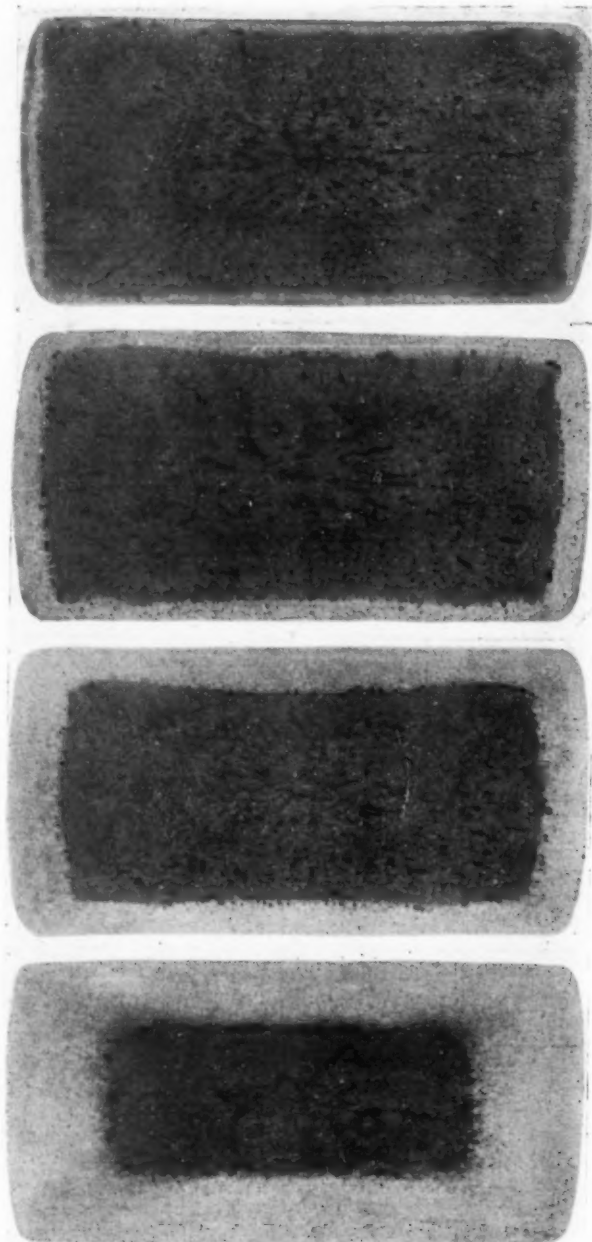

Fig. 2.—Control of rimming steel. The rimming action was stopped after 1 min. 15 secs., 5 mins. 40 secs., and 8 mins., respectively in the first three sections. The fourth section is full rimming steel.[*]

above that required in the steel, there is very little hope of successful rimming, and the charge should be diverted to a killed soft grade. The proper melt is one that allows some oxide to be fed, sufficient to promote and maintain a proper boil. Steel that has not boiled properly will not rim well. The amount of FeO in the slag at the finishing point is generally considered to be an important factor. The desirable amount varies from plant to plant. Some operators prefer to keep the FeO below 18%, while others work up to about 22%. Control of slag condition is, therefore, established by each plant as a result of experience with the particular raw materials available.

The quantity and type of deoxidisers used is naturally of

8 *Metal Progress*, 1939, vol. 35, p. 167.

9 Ninth Report on the Heterogeneity of Steel Ingots. Iron and Steel Institute Special Report No. 27.

great importance. Provided that reasonably standard conditions of melting practice are maintained, one can apply a schedule of additions, based on the carbon content of the bath and the iron content of the slag, that will ensure approximately standard rimming conditions. The use of silicon is commonly avoided, the deoxidation being done with manganese up to the specified limit and aluminium in the quantities dictated by experience. These additions are usually made in the ladle, and are designed to leave a very small aluminium addition to be made in the moulds.

The temperature at which the steel is finished has an important bearing on the rimming action. It is accepted that a high casting temperature leads to retention of gas and the formation of a thin skin.

The behaviour of the steel in the moulds gives an indication of the type of rim that will be formed. For the formation of a thick rim the steel should rim-in at the original pouring level. This is the standard condition usually aimed at, and will be attained where furnace practice, deoxidation practice, and steel temperature have run in the established channel. A steel deficient in effervescing power will rise in the mould ; this condition may be brought about by (a) soft melt and insufficient boiling ; (b) too high temperature ; (c) too much deoxidation. Nothing much can be done to correct this condition, but some operators make use of sodium fluoride, which tends to promote gas evolution. If the steel has too great a power of effervescence it will sink in the mould and will not rim-in smoothly. The usual practice, however, is to make the steel so that it has a slight tendency to sink, and to make an addition of aluminium pellets in the mould, the amount being judged by the teemer, so that the sinking tendency is suppressed.

The rimming may then be controlled to give any desired thickness of rim up to the maximum. If the rimming action is allowed to proceed uninterrupted it will produce a rim of maximum thickness for the type of steel ; but if it is desired for any particular purpose to have a thinner rim and a wider distribution of the impurities, the rimming action may be stopped at will. This is usually done by putting an iron cap or a steel plate on the top of the effervescing ingot when it is judged that the desired depth of rim has formed. The result of this type of control is illustrated in Fig. 2.

Rimmed ingots can be satisfactorily made in moulds of a large variety of sizes and shapes. Bottom pouring is sometimes used with the object of avoiding splash and controlling the filling rate. The moulds used are generally narrow end up. The author believes this practice to be best, because the rim obtained in these moulds has a more uniform thickness through the length of the rolled product than is the case when wide-end-up moulds are used.

Control of Grain Size.—It is only in the last few years that the control of grain size as a specific technique has been applied to large tonnages of steel in this country. For more than ten years there has been an extensive American literature on the subject ; interest in this country received a great impetus following a paper read in 1936 by Dr. T. Swinden and G. B. Bolsover.[10]

The demand for steels of controlled grain size came mainly from operators of heat-treating processes—for example, the motor-car industry, where vast numbers of small parts were required to exhibit constant behaviour under physical tests after heat-treatment. Lack of uniformity between one piece of steel and another was commonly noticed by heat-treaters, and the difference in properties was often ascribed to the lack of " body " in one of the steels. Abnormal results are virtually eliminated by the use of fine-grained steels for such work, but it is not claimed that fine grain is the simple answer to the production of steel having more body.

The grain size that is subject to this comparatively new

control is, of course, the inherent grain size, or the size of the austenitic grain developed at a given temperature. The size is measured by carburising a sample of the steel under standard conditions of time and temperature, and examining the carburised case at a magnification of 100 diameters on a projection microscope. A clearly defined grain size is observed and, by comparison with a standard chart showing typical fields for each grain size, the grain size of the sample may be estimated. The grain size number or index, N, bears a relation to the number of grains, n, per sq. in. of image at 100 diameters. The basis of the numbering system is $n = 2^{N-1}$, and each higher number indicates twice as many grains per sq. in. as the previous one.

The numbers normally range from 1 to 8. In America, grain-size control is exercised to produce coarse or fine grain, up to size 5 and above size 5. Swinden and Bolsover report that normally it is possible to control to within three sizes. Control to this extent appears to be sufficient. One user of steel for heat-treating reported that with steels of grain size 4, 5 and 6 no departure from standard heat-treatment was necessary, but that an alteration had to be made when grain size 2 to 3 was received.

Steel of controlled grain size is made by mould additions of aluminium to steel which has been carefully deoxidised in the furnace. Such aluminium additions are in no sense a corrective for imperfectly made steel, nor do they make the steel " dirty." Proper deoxidation practice in the furnace is essential to the success of the operations, and if this is done the necessary aluminium addition will not increase the content of non-metallic inclusions.

The principal advantages in the use of steel of controlled grain size are increased toughness, greater uniformity under heat-treatment, and surer standardisation of machine-shop practice.

Low Alloy Steels.—The basic open-hearth process is being successfully used for the manufacture of a variety of low-alloy steels. Many of these steels are designed to replace plain carbon steels for structural work, where equal strength and toughness are required with decreased weight, or to give high fatigue values under severe service, or high resistance to corrosion. The use of carbon-manganese steels has recently rapidly expanded. Manganese varies from about 1·4% to 1·8%, while the carbon falls generally into three ranges. The lower carbon steels containing 0·10 to 0·15% of carbon are used in normalised form for general engineering work, where high shock resistance is essential, such as haulage gear, etc., whilst in case-hardened form they are applied extensively to gear-wheels, shafts, etc. A carbon range of 0·20 to 0·27% provides steels with tensile strengths of up to 44 tons per sq. in., which find extensive use in shipbuilding and structural engineering, using riveted or welded methods of assembly. In the range 0·30/0·40% carbon, these steels in the hardened and tempered condition provide useful low-priced substitutes for some of the more highly alloyed steels, and are used for such purposes as automobile crankshafts, front axles, etc.

Steels with about 1% each of chromium and manganese and about 0·3% of copper are in use as corrosion-resisting structural steels. These, and the carbon-manganese alloys, are habitually made in the basic open-hearth furnace. The required mechanical tests are specified in a fairly narrow range, hence chemical specifications must be adhered to and ingot soundness must be obtained. The melting practice must be properly controlled, with particular regard being paid to the finishing of the heats. The addition of large quantities of alloy is best made, for the sake of uniformity of analysis, in the furnace rather than in the ladle. But the addition of oxidisable alloys, such as manganese and chromium to the bath, must be accompanied by well-controlled bath conditions. The feeding of the bath, its boiling period, and hence its state of oxidation, must be controlled on established lines. Heats are usually blocked with spiegel, and the slag limed up before the alloy additions. Failure to achieve regularity in these particulars

10 T. Swinden and G. R. Bolsover. *Journal of the Iron and Steel Institute*, 1936, No. 2, pp. 457 P.

will result in erratic losses of alloys and consequent misfits. If the additions are made to the ladle it is easier to hit the analysis, but not so easy to achieve the necessary homogeneity. Chromium in the form of ferro-chrome is a fairly refractory material and is commonly added in the furnace. Some success has been achieved in America and in this country with a material known as Chrome—X.[11] This material is made from ground ferro-chrome-silicon, mixed with calcined chromite and a suitable igniter. It is added to the ladle, where its reaction is exothermic. Its use has resulted in a saving of time and of chromium. This latter saving has been estimated at 6%, and is due to the addition being made in the ladle instead of in the furnace.

Nickel steel, nickel-chrome. and nickel-chrome-molybdenum, have for many years been successfully made in the basic open-hearth furnace. Where non-oxidisable elements such as nickel and copper are concerned the manufacture does not present the same hazard as where a large and easily variable loss of alloy can occur by oxidation. The development of the use of low-alloy steels, accelerated no doubt by the war, will, in the author's opinion, lead to the permanent replacement of carbon steels for many purposes. The basic open-hearth furnace will in the future make greatly increased tonnages of this class of steel.

Variations in pitside technique are sometimes necessitated by alloying additions. Reladling is usually resorted to in the manufacture of high silicon alloys ; the 2% silicon, 1% manganese spring steel is tapped through two ladles, while three ladles are often used for 4% silicon steels destined for the electrical industry.

Brief mention should be made of stainless steel. In the last few years stainless has been made in the open-hearth furnace in America,[12] but to the best of the author's belief the process is not running on a commercial scale. An unusual design of furnace was built to attain the necessary temperature, and furnace campaigns were excessively short. It is possible that the answer to this problem lies in the all-basic furnace.
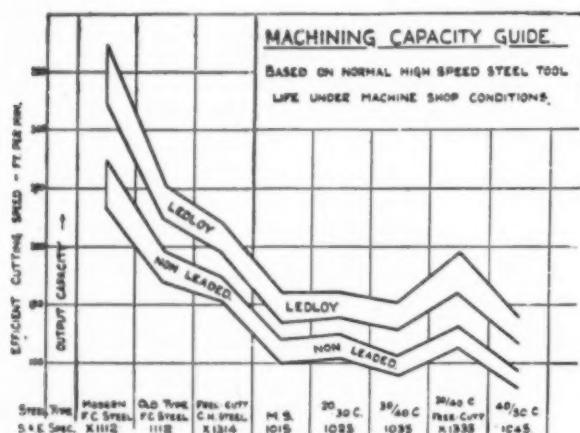

Fig. 3.—Economic cutting speeds for different grades of steel, with and without a lead content.

Lead-bearing Steels.—Steels to which about 0·20 to 0·25% of lead has been added are being used in increasing quantity. The lead confers on the steel a greatly enhanced machinability, varying from 20% to 100% and averaging about 40%,[13] without imposing any substantial alteration in physical or chemical properties. The lead is not soluble in steel, but is present principally as metallic lead in a very finely divided state.[14] The lead particles act partly as chip breakers and partly as lubricators. The general influence of a lead content on machinability is illustrated in Fig. 3.[15] The necessary amount of lead to give about 0·25% is

added in the form of lead shot or as lead oxide to the moulds, the addition being made progressively as the mould fills. The lead distributes itself fairly uniformly over the mass of steel, the amount of heterogeneity being less than that of sulphur and phosphorus, but similar in design. Fumes of lead oxide are given off and are conducted away from the vicinity by exhausters operating through hoods over the moulds. Health hazards are by this means completely eliminated. This aspect of the matter has been fully dealt with by E. D. Martin.[13]

The Perrin Process.—The process of deoxidising or dephosphorising molten steel by mixing it with suitably prepared slag was devised and patented by Mr. R. Perrin, of Ugine, France. The process takes advantage of the remarkable speed with which metallurgical reactions take place when the reactants are brought into sufficiently intimate contact.

The extremely rapid reactions in the Bessemer process are of course brought about by the application of the same principle, while the comparative slowness of the open-hearth process is due mainly to the lack of intimate admixture of the reactants. The use of the Perrin process in the production of large tonnages of steels was discussed by Yaneske in 1940.[16] The role of the open-hearth furnace in the process he described is to make slag of the desired composition, and therefore the furnace, without making any steel itself, fulfils an essential part of the operation. The author holds the opinion that the Perrin process in some form will contribute to open-hearth practice ; indeed, the rapid reactions that are obtained in the Talbot and Monell processes are virtually applications of the same principle. The urge to quicken steelmaking operations inevitably leads to attempts to improve the intimacy of contact of the reactants.

16 B. Yaneske. *Journal of the Iron and Steel Institute*, 1940, No. 11, p. 35 P.

Iron and Steel Institute

A joint meeting of the Sheffield Society of Engineers and Metallurgists, the Sheffield Metallurgical Association, and the Iron and Steel Institute has been arranged to be held at the Royal Victoria Station Hotel, Sheffield, on Saturday, October 24, at 2-30 p.m. Dr. W. H. Hatfield, F.R.S., Vice-President of the Iron and Steel Institute, and President of the Sheffield Society of Engineers and Metallurgists, will occupy the chair, and the following papers will be presented for discussion :—

" The Formation of Hair-Line Cracks, Part 1," by Professor J. H. Andrew, D.Sc., A. K. Bose, B.Met., G. A. Geach, M.Sc., Ph.D., and H. Lee, B.Eng., Ph.D.

" The Determination of the Solubility of Hydrogen in Iron and Iron Alloys," by Professor J. H. Andrew, D.Sc., H. Lee, B.Eng., Ph.D., and A. G. Quarrell, BSc., Ph.D.

11 A.I.M.M.E. Open-Hearth Proceedings, 1941, p. 84, *et seq.*
12 J. C. Vignos, " Blast Furnace and Steel Plant," 1938, vol. 26, Jan., p. 62.
13 E. D. Mart'n, *Metal Progress*, 1939, May, p. 457, *et seq.*
14 METALLURGIA, 1939, July, pp. 95-98.
15 METALLURGIA, 1941, Aug., p. 100.

Electro-Tinplate[*]

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(*Tin Research Institute*).

Electro-tinning is a recognised industrial process, but its application in the production of tinplate is a comparatively recent development. In concluding his review of the process, the author indicates its possibilities for conserving tin without undue reduction in the quality of the tinplate. Notes on American practice are given.

WIDE programmes of research and development on electro-tinning have been carried out both in Great Britain and in the United States, but it is the latter country that has, so far, chiefly developed the manufacture of tinplate by the electrolytic process. This development has been stimulated by the absence of domestic supplies of tin in the States and by the fact that it has not so far been found practicable to tin continuous strip in wide widths by the hot-dip method.

Cold-reduced Strip

So far as is known, all electro-tinplate plants operating, building or projected in the United States are based on using cold-rolled strip as the raw material of the plating process. In Great Britain cold-reduced tinplate basis is often referred to as " white-to-edge " plate, or sometimes " Ebbw Vale " plate, since the only present domestic source of the product is Messrs. Richard Thomas and Co.'s strip mill at Ebbw Vale. The material is quite distinctive in appearance, having a smoother and brighter surface, and being free of the visible oxide film and blue edges of the ordinary pack-rolled tinplate basis. The final operations in the manufacture of strip tinplate basis are as follows : Hot-rolled strip is decoiled and pickled in continuous pickling lines. After washing and oiling the strip is cold-reduced to finish gauge in four-high tandem mills or in single-stand reversing four-high mills. Rolling lubricant is then removed from the strip in continuous electrolytic degreasing plants, and the material is coiled up and annealed in radiant tube controlled atmosphere close-annealed furnaces. The annealed strip is then subjected to a skin-pass rolling operation or temper-rolling. No rolling lubricant is used at this stage in order to avoid contaminating the strip with oil, which might be difficult or inconvenient to remove prior to subsequent coating processes. It is interesting to note that the surfaces of the rolls for temper rolling may be finished to a matt surface by shot-blasting or by other means. This imparts a slightly roughened surface on the finished strip which is particularly suited to subsequent coating operations. Before hot-tinning, strip is cut to tinplate sizes on a flying shear. If, however, the electrolytic process is to be used, then the strip is passed to the coating operation in coil form.

The general production problem has been well summarised by M. D. Stone as involving electro-tinplating cold-rolled, annealed and temper passed low-carbon mild steel strip with a coating weight of ½ lb. per basis box (0·00003 in. thickness), at 500 ft. per min., the strip being from 0·007 in. to 0·011 in. thickness, 16 in. to 38 in. wide, in coil lengths of 5,000 ft. to 10,000 ft., and coil weights of 6,000 lb. to 12,000 lb. It can be added that associated problems are concerned with the production of thinner coatings of the order of 0·1 lb. basis and with the perfection of after treatments, such as flow-brightening (flash melting), buffing and oiling.

Preparation of the Strip

The quality of any electrolytic coating depends in very large measure on the characteristics of the surface of the

basis metal. Cold-reduced steel strip has a grease-free and oxide-free surface, but it is often considered desirable to provide for a short electrolytic degrease prior to the essential, though usually light, pickling treatment. In the semi-scale pilot plant (acid process) described by Stone (loc. cit.) provision is made for a 34-ft.-long electro-cleaner, followed by a 70-ft.-long acid etch tank in front of the 90 ft. plating tank. Each tank is followed by a scrubbing and rinsing station, and the strip is normally given about 3 secs. in the detergent solution and 5 to 10 secs. in the dilute sulphuric acid pickle.

The function of the acid pickling is rather to provide an etched surface than to remove scale, the adhesion between the coating and the basis metal being thereby improved. The electrolytic cleaning may be omitted and preparation is then confined to a continuous pickling operation : thus in one plant the strip is pickled electrolytically in 10% sulphuric acid at 200 amperes per sq. ft. In other cases, certain required qualities in the finished product have dictated the need for more intensive cleaning of the strip surface prior to plating. As an example, E. W. Hopper, assignor to the Crucible Steel Co., makers of Crutin electro-tinplate, outlines in U.S.P. 2,274,963 a series of preparative operations involving electrolytic cleaning, acid pickling, scrubbing, annealing or normalising, pinch rolling, electrolytic recleaning, scrubbing, and repickling. Steps prior to the annealing operation may be omitted, but the complete series of cleaning treatments is said to give a basis material suitable for producing alkaline-plated and flow-brightened electro-tinplate of very high quality. Sodium orthosilicate is used for the electrolytic cleaning baths, hydrochloric acid or sulphuric acid for the first pickling operation, and 17% hydrochloric acid at 88° C. for the final pickling.

Acid Bath Installations

Although exact compositions of the plating solutions used in electro-tinplate manufacture are not usually disclosed, it may be judged that they are, in general, of fairly straightforward type, modifications being mainly concerned with types of addition agents and with the concentrations best suited to high-speed plating. The acid bath would appear to be rather more popular at present, but the alkaline process has some strong advocates. A neutral or slightly acidic chloride electrolyte has been recently put forward by du Pont and pilot-scale experiments are in progress. A fluoride electrolyte is proposed by Nachtmann, and a narrow electro-tinplate line which will use this electrolyte is being erected.

Numerous plants based on the acid process are in building or operation. The " Ferrostan " electro-tinning plant at Carnegie-Illinois' Gary Works has been described recently by T. W. Lippert. This plant was an early-comer, and during its three years of existence is stated to have produced over three million boxes of electro-tinplate. Examination of samples of plate from this plant shows the material to have a semi-matt surface with a slight sheen, good soldering quality, and fairly high corrosion-resistance. The plant uses strip of normal tinplate gauge and about 28 in. wide. Speed of operation is at least 250 ft. per min., and the overall length of the plant is 140 ft.

The composition of the acid tin-plating solution is based on patents and rights held by the United States Steel Corporation, and is of the phenol-sulphonic acid type. About 20 ft. of strip is in the electrolyte at one time in four vertical passes of 5 ft. each, the strip being taken up and down over suitable rollers. Provision is made for circulation of the electrolyte, and this, together with the rapid movement of the strip, provides agitation allowing the high current densities of up to 200 amperes per sq. ft. The bath has a capacity of about 3,850 gals., and contains over half a ton of tin in solution. When the strip leaves the plating tank drag-out electrolyte is washed off with high-pressure sprays, continued with squeegees, and the coating is then scratch-brushed with nickel-silver brushes in a precision burnishing machine. Finally, the plate is dried and passed through a continuous branning machine. The bran or similar material carries a little palm oil and imparts a light oil film to the strip surface. The light oil film has protective quality, acts as a die lubricant in stamping, and is said to assist de-piling body blanks. If the strip is required to be flow-brightened it is passed through a resistance flash-heating unit which brings the coating to a temperature just above its melting point, after which it is rapidly cooled.

caps and bottle seals, and requires to be of suitable quality for the decorating, stamping and varnishing operations which this usage involves. In over a year's successful operation, the plant has produced more than a million boxes of plate, general run of coating thickness being less than ½ lb. per basis box.

The lower current densities used in the alkaline process, 35 ampere per sq. ft. in the present case, involve the arrangement of more lengthy strip travel in the plating tank in order to achieve reasonably fast line speeds. The plating unit is arranged with 16 vertical up-and-down passes of 12 ft. each, equivalent to 384 ft. of strip in the plating tank at one time. A linear speed of 250 ft. per min. is achieved, and in future lines of similar type higher speeds may be realised by using a larger plating unit. The operating temperature is about 85° C., this fairly high temperature enabling maximum current density to be used without loss of efficiency. Heat input is provided by steam coils at the bottom of the tank and the electrolyte is not circulated other than by removing it at one end of the tank for filtering and returning the clean electrolyte at the other end. Very large anodes, requiring removal only about once a month, hang between the vertical strands of moving strip.

Strip leaving plater and drag-out reclamation and proceeding to finishing line comprising burnishing machine, hot rinse, drier, looping pit, branner, shear, and coilers.

← Strip entering unit after preparative operations in attached line comprising decoilers, shear, welder, looping pit, electrocleaner, acid etcher, scrubber.

(M. D. STONE loc. cit.)
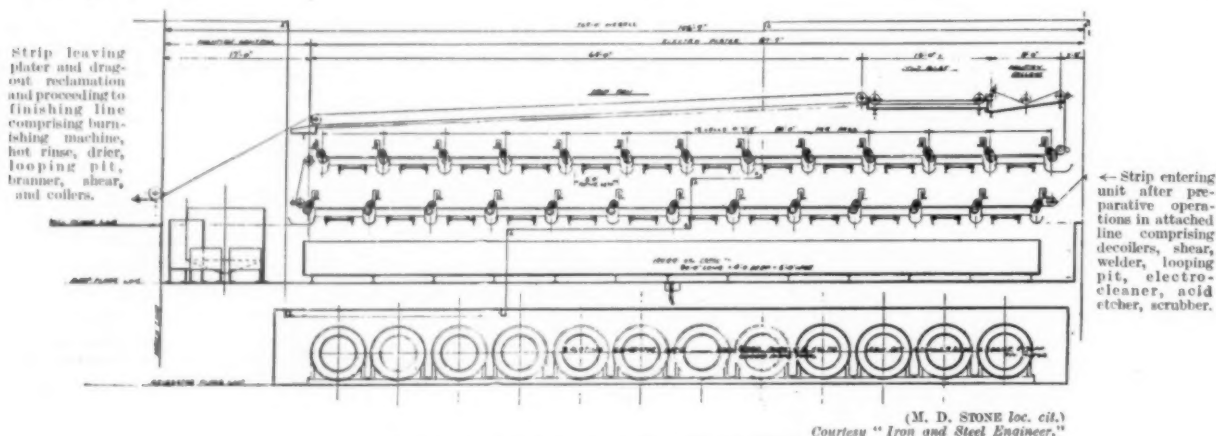Courtesy " Iron and Steel Engineer."

Fig. 1.—Plating unit of strip electro-tinning line

A strip-plating plant must be so designed that impurities from the anodes, sludge, and any disintegrate particles from anodes do not fall on to the strip during the plating operation. This may be ensured by plating the strip in a series of vertical passes, or by having a single horizontal pass with the strip width vertically on edge, or, as in the pilot-scale installation described by Stone, plating from the underside only (Fig. 1).

The plating tank of the latter plant is shown in Fig. 1. The following operations precede plating : Uncoiling, end shearing, seam welding, looping pit, electro-cleaning, acid etching, scrubbing. After plating and rinsing the strip passes through the scratch-brushing machine, hot rinse and oiling branner, and is finally coiled up. The plating plant has three 84 ft. horizontal stages, one above the other. The strip passes over the first 12 plating cells when one side is plated, then turns over and proceeds in the reverse direction over the second series of cells and finally reverses again and passes through the solution reclaim and rinse tanks and over a long drip tray to the burnishing machine. High-speed circulation of the electrolyte in the vicinity enables current densities upwards of 500 amperes per sq. ft. and close proximity of anodes and cathode provides low ohmic resistance with consequent power economy.

Alkaline Plant

The manufacture of strip electro-tinplate is exemplified by the Crown Cork and Seal Co.'s plant. The product is used by the company for its own manufacture of crown

Solution dragged out on the issuing strip is removed by squeegee rollers and water sprays, and the diluted drag-out is returned directly to the bath to make up evaporation losses. After leaving the drag-out reclamation system, the strip is washed, rinsed in hot water, and dried by hot air. The coating has a smooth matt surface and part of the production may be flow-brightened (q.v.).

Crutin Plant

The plant at the Crucible Steel Co.'s Pittsburgh Works is a recognised pioneer in the electro-tinplate field. Built over five years ago, the project aimed at the production of a material of superior quality to hot-dipped plate in coil form. Tin-saving was, perhaps at that time, a secondary consideration, but now the experience accumulated over a long practical running period is of inestimable value.

Various schemes of operation may be practised. Thus the advantages of both types of bath may be secured by plating an initial alkaline deposit and building-up from an acid electrolyte, while for a special grade an electro-copper alloy undercoat is used. The material is flow-brightened, and three grades of electro-tinplate are regularly produced in coil lengths varying from 4,000 ft. to 7,000 ft. One grade carries about 1 lb. per basis box and has general fabricating characteristics and corrosion resistance comparable with or superior to hot-dipped coke-grade plate. A more economical grade, carrying 8 oz. per basis box, is a high quality product in view of the economical coating weight and in some cases has been reported to be practically

equivalent to coke-grade hot-dip plate. The third grade was originally brought out for specialised applications, but its range of usefulness is wide. This is the material with the copper alloy undercoating, and very high protective value is claimed.

Other undercoating metals—for example, electro-iron and electro-nickel—have been proposed and used elsewhere. The principle is that a very homogeneous surface of suitable characteristics, excellent adhesion, and high continuity in the final tin coating, can be produced by plating a relatively inexpensive metal on to the cold-reduced strip prior to the tin-plating operation. In some cases the undercoat may be fritted on to the basis metal by heating in a controlled atmosphere after electro-deposition.

Flow Brightening

The process of flow brightening is of pre-eminent interest, since it would appear to have the inherent possibility of providing a material having many of the advantages attached to both the electro and hot-dip processes. Flow brightening (*flash-melting* and *thermal re-flowing* are synonymous terms) involves raising the electro-deposited coating to a point just above its melting temperature for a comparatively short time ; the treatment being claimed to improve appearance, lacquering and fabricating quality, and corrosion resistance. Provided that the process is correctly carried out, it is considered that these claims are likely to be substantially true. Examination of samples brought to this country, which of course may or may not be exactly typical of the general run of quality, show the porosity of flow-brightened electro-tinplate to be substantially better than that of straight deposited plate of like coating thickness. Improvement of appearance is, of course, beyond question, and the surface is resistant to finger-marking. Resistance to atmospheric corrosion in storage is excellent, but it cannot be stated, on the somewhat narrow basis of samples seen, to be significantly superior to burnished and oiled plate in this particular respect. Flow-brightened coatings carry an alloy layer of about 1 oz. of $FeSn_2$ per basis box.

In the flow-brightening process it is found that the coating should be above its melting point for a very restricted period only, since if sufficient time is available the tin coating will " de-wet " or aggregate into a number of minute globules or streaks, with consequent degeneration in appearance and increase of porosity. The reason for this is that tin coatings on steel, whether electro or hot-dip, generally tend to de-wet when molten, and it is only by using expedients to restrict this tendency that smooth fusion coatings are obtained—viz. :—

(1) By keeping the time during which the coating is molten as short as possible. De-wetting involves movement of fluid tin and the magnitude of the effect is lessened if the time for movement is restricted.

(2) By mechanically restraining the movement of fluid tin as by using heated rollers to effect fusion.

(3) By so preparing the steel surface prior to plating, as by intensive cleaning, etching, and also by precoating with other metals (electro-nickel, copper, etc.), that the interfacial tension tin-basis metal is reduced, and with it the tendency to de-wet. Careful preparation would also tend to reduce the number of nuclei at which de-wetting could originate.

(4) By fusing the coating under an oil which reduces the surface tension of molten tin.

These various devices have been employed and fairly detailed accounts of practice may be read in papers noted in the bibliography at the end of this review. Insufficient process data have yet been accumulated for practice to be finalised, but a number of successful plants are in operation and many more are projected.

Various methods of heating and cooling the strip are used. In the flow-brightening equipment attached to the Crown Cork Company's alkaline plating line the strip is flowed in a vertical radiant-tube controlled atmosphere furnace and thereafter rapidly quenched in water. Resistance heating and induction heating are other favourable means of heating the strip used by other manufacturers. In U.S. Patent 2,274,963, E. W. Hopper describes an oil-bath for flow-brightening, wherein a short fusion time is achieved by using a double reservoir of oil. The two compartments are connected by a narrow sloping duct through which the strip passes from the hot oil section to the cold oil section. The sloping duct, which has its opening into the cool oil section at a lower level than its connection to the hot oil section is an ingenious means of providing an effective seal, preventing thermal exchanges between the two baths. Rapid freezing of the fused coating is thus made possible. Palm oil, which reduces the surface tension of tin, is used.

Broadly stated, the practice of flow-brightening involves delicate temperature control of strip moving at high speeds, plus a sound appreciation of the physical and metallurgical fundamentals governing the flow of liquid metals. It is the writer's opinion that the future of electro-tinplate is greatly dependent on the practical perfection of after-treatments, in particular the flow-brightening process. Straight deposited thin electro-tinplate is an excellent and valuable war-time expedient, but the brilliant and corrosion-resistant coatings promised by perfected thermal after-treatments will perhaps have wider application in the development of efficient metal packages in the post-war period.

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Dr. L. R. Underwood, D.Sc. (Eng.), Ph.D., has resigned his position of Chief Engineering Officer to the Rolling Mill Technical Department of the British Iron and Steel Federation to join the technical staff of W. H. A. Robertson and Co., Ltd., Lynton Works, Bedford.

Bearings for Diesel Engines

In selecting substitute bearing materials, investigations have shown that experience and actual performance factors are of major importance, and data are given which are based primarily on these factors.

IT is generally recognised that there is no universal bearing material which is good for any and all installations. Each available material has its own field of usefulness, and it must be used within the limitations of that field if optimum bearing performance is to be obtained. In normal times, Willi* states, five types of lining materials are used in bearings for Diesel engines, comprising :—

    Tin-base babbitt of several compositions ; in combination with back structures of steel, bronze, and cast iron.

    Lead-base babbitt of several compositions ; in combination with back structures of steel, bronze, and cast iron.

    Cadmium-silver-copper bearing alloy ; in combination with steel backs only.

    Copper-lead mixtures ; in combination with steel backs only.

TABLE I.
CHART SHOWING FIELD OF USEFULNESS FOR VARIOUS BEARING METALS.

Description of Bearing Metal.	Maximum Permissible Unit Pressure.	Minimum Permissible Zn/P max.	Maximum P max V.	Oil Reservoir Temp.	Minimum Crankshaft Hardness.	Affected by Corrosion.
Tin Base Babbitt. Copper.....3·50% Antimony .. 7·50% Tin........89·00% Lead (max.), 0·25%	1000 p.s.i.	20 *Standard quality	35000 bearings.	235° F.	Not important	No
Tin Base Babbitt. Same composition as above	1500 p.s.i. † Alpha	15 process qu	42500 ality bear	235° F. ings.	Not important	No
High Lead Babbitt. Tin ...... 5 to 7% Antimony, 9 to 11% Lead .. 82 to 86% Copper(max.)0·25%	1800 p.s.i.	10	40000	225° F.	Not important	No
Cadmium-Silver. Silver ..... 0·75% Copper ...0·50% Cadmium, 98·75%	over 1800 and up to 3850 p.s.i.	3·75	90000 and upwards	260° F.	250 Brinell	Not likely if temperature is maintained as specified and proper lubricating oil is used
Copper-Lead. Copper........65% Lead 35%	over 1800 and up to 4500 p.s.i.	3·75	90000 and upwards	260° F.	300 Brinell	

* "Standard-quality" bearings are those which are produced as competitively priced products.
† "Alpha Process" quality bearings are those which are produced by such methods as will result in maximum performance expectancy, and with cost a secondary consideration.

TABLE II.
LINING THICKNESSES FOR DIFFERENT SHAFT DIAMETERS.‡

Shaft Diameter, In.			Lining Thickness, In.	
			Minimum.	Maximum.
0	to	2½	0·020	0·025
2⅝	to	3½	0·025	0·030
3⅝	to	4⅞	0·030	0·035
4¼	to	6	0·040	0·045
6⅛	to	11	0·060	0·070

‡ Tin- and lead-base babbitt ; cadmium-silver-copper and copper-lead bearings.

TABLE III.
RECOMMENDED OIL CLEARANCES FOR VARIOUS BEARING MATERIALS.

For tin-base and lead-base babbitts, based on 0·0005 per in. of shaft diameter.
For cadmium-silver copper, based on 0·00080 per in. of shaft diameter.
For copper-lead, based on 0·0010 per in. of shaft diameter.

The field of usefulness of these various bearing metals is defined elsewhere[1] and reproduced in Table I. These values obtain in combination with pressure lubrication and lining thicknesses, as defined by Bassett,[2] and given in Table II. It is also necessary to define the associated oil clearances given in Table III. It is further necessary to qualify the maximum load ratings by the influence of the length-to-
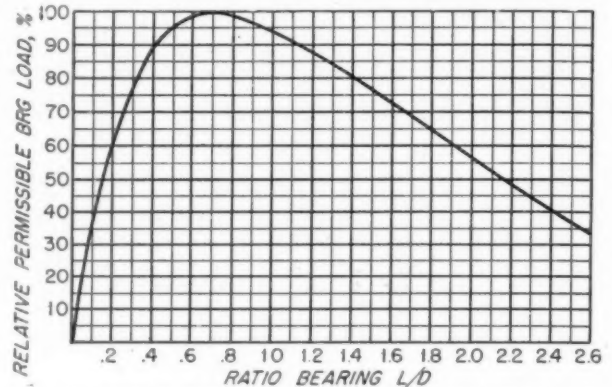
* Paper presented at National Meeting of Oil and Gas Power Division of the American Society of Mechanical Engineers, June, 1942 ; see *Mech. Eng.*, 64, 6, pp. 439–448.
1 A. B. Willi, "Engine Bearings from Design to Maintenance." S.A.E. Transactions, vol. 34, 1939, p. 513.
2 H. N. Bassett, "Bearing Metals and Alloys." Edward Arnold and Company, London, 1937, p. 87.

Fig. 1.—Relative permissible bearing load plotted against L/D ratio.
(From Automobiltzchnische Zeitschrift, Sept., 1932.)

diameter (L/D) ratio. As shown in Fig. 1, the L/D ratio for maximum efficiency is 0·7. Load-carrying capacity drops off very rapidly as L is reduced, and considerably less rapidly as L is increased. It must be kept in mind that a bearing divided by an internal annular oil groove is in fact two bearings, in so far as oil film formation is concerned. The influence of the L/D ratio in affecting load capacity must be applied in each section of the separated bearing surface.

Under present conditions it is not always possible to select the most suitable bearings for a given engine. The use of tin and cadmium is seriously restricted, which necessitates that the use of other metals such as lead and copper must be extended, and even these are not available in unrestricted quantities. The most likely substitute for tin-base babbitt is lead-base, and although opinions have been expressed that do not show the lead-base alloys in a favourable light, the situation with respect to its substitution for tin-base babbitt in oil or petrol-engine bearings is not at all gloomy. It is not possible to say that any lead-base babbitt can replace any tin-base babbitt under any and all conditions, but it is possible to specify certain lead-base babbitts, applied under defined conditions, which will replace certain tin-base babbitts, and obtain improved performance. There has been a definite trend in this direction for several years, and many petrol and oil engines have been regularly produced with lead-base-babbitt main connecting rod and camshaft bearings. The reason for this trend has been improved performance.

As an alternative to cadmium-silver-copper or other cadmium alloy bearings, the selections will lie between a lead-base babbitt and a copper-lead mixture. The choice is likely to be a compromise in which availability must take precedence over performance.

It does not seem reasonable to expect that the substitutions can be made in wholesale fashion without catering to the conditions under which the substitute materials may best work. This can be illustrated by the behaviour of a selected group of bearing materials under operating conditions. It is not possible to present a detailed picture which covers all the ramifications and variables of material composition, lubrication, loads, speeds, etc., but it is possible to examine the behaviour of certain selected bearing metals which have been successfully used in Diesel-engine production.

In his report, Willi shows a comparison of four types of bearing metals with respect to coefficient of friction,
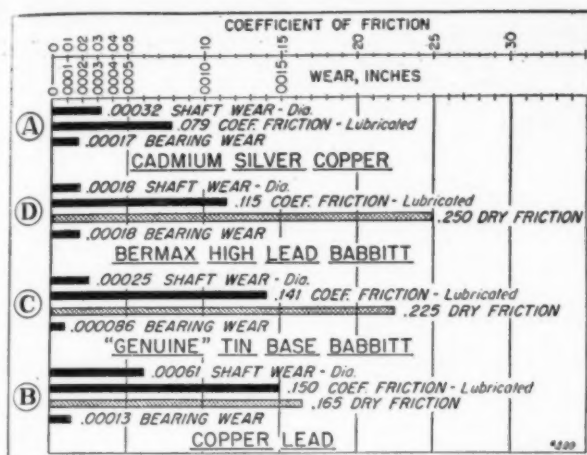
Fig. 2.—Comparison of four types of bearing metals.

lubricated and dry, shaft wear, and bearing surface wear. This is reproduced in Fig. 2. The chemical analysis of the bearing metals used are as follows :—

(a) Cadmium-silver copper : Silver, 0·75% ; copper, 0·50% ; cadmium, balance.

(b) Copper-lead : Copper, 70% ; lead, 30%.

(c) Genuine tin-base babbitt : Antimony, 7·5% ; copper, 3·5% ; tin, 89%.

(d) Bermax high-lead babbitt : Antimony, 9 to 11% ; tin, 5 to 7% ; copper, 0·25% ; lead, balance.

The coefficient of friction (lubricated) values were obtained on a modified Herschel oiliness machine. The dry friction coefficients were taken, using a slider with three highly polished ball contacts operating against a flat surface of the bearing metal mounted on an adjustable inclined plane. The shaft and bearing wear values were taken from a series of six-cylinder engine tests, under specified conditions. The lining thickness in all bearings was 0·013 in. to 0·018 in.

Shaft wear with cadmium-silver-copper bearings was high—namely, 0·00032 in.—and this is accounted for on the basis of low shaft hardness. A Brinell hardness of 250 is recommended for this material, and the test shafts were 226 Brinell. Shaft wear with the copper-lead bearings was worse—namely, 0·00061 in.—and this is also accounted for on the basis of low shaft hardness. A Brinell hardness of 300 is recommended, while the test shafts were 246. The lower shaft wear with the Bermax high-lead bearings, as compared with the tin-base babbitt bearings, can reasonably be attributed to the lower coefficient of lubricated friction. The differences in bearing wear do not match with coefficient of friction values, and these differences are attributed to the individual characteristics of the metals.

A comparison of the temperature rise at the surface of four types of bearing metals is made as a result of twelve tests. The Bermax high-lead babbitt, tin-base babbitt, and copper-lead bearings were similar to those in Fig. 2. Aluminium-alloy bearings containing approximately 7% tin were included. From these tests it was concluded that under conditions of good lubrication and moderate loads the temperature rise for the four types of bearings was very closely within the range defined by the tin-base babbitt bearings. Investigations showed that the lead-base babbitt bearings tested require more lubrication than the tin-base babbitt.

Endurance tests on a number of bearings have been carried out, and it is interesting to note that, under the conditions of this test, the Bermax high-lead babbitt bearings showed considerably improved performance over the tin bases. Three other types of lead-base babbitt bearings were included in this test, one of which showed itself to be superior to tin-base babbitt in many applications, the others confirmed past experience, which has shown tin-base babbitt superior for heavy duty work.

From this review of the physical properties of selected bearing metals, which includes friction, wear, surface temperature, dry-shaft performance, elongation, tensile strength, Brinell hardness, and bond strength, it is evident that none of these properties offers a reliable and easy guide for predicting the performance of dissimilar bearing metals. This means that in selecting substitute materials " experience and actual performance factors " will be of major importance. The rating chart, Table I, was primarily based on these factors.

A Lithium-Bearing Silver Solder

The need for a silver solder for brazing tungsten-copper alloys, containing a high percentage of tungsten, has prompted an investigation which has resulted in the development of a lithium-bearing silver solder and data on results of tests are given.

INVESTIGATIONS by F. R. Hensel, E. I. Larsen, and E. F. Swazy* on tungsten-copper alloys have shown that these alloys offer excellent possibilities for electrical purposes, such as welding electrodes and electrical contacts, due to the physical and chemical properties of the different alloy combinations. The silver brazing of comparatively large sections of these alloys, containing a high percentage of tungsten is difficult, since this type of refractory contact material has a tendency to oxidise rather rapidly during the brazing operation. It is also difficult to obtain proper wetting action of the refractory metal particles, because tungsten does not alloy readily with the elements commonly used in the composition of silver solders. The need for an improved silver soder for this particular class of material prompted a further investigation,[1] which has resulted in the successful development of a lithium-bearing silver solder for that purpose, and the results of tests with this brazing alloy for joining ferrous and non-ferrous alloys have been discussed recently by the investigators.

A preliminary series of tests were made on content materials with a standard silver solder to which was added various percentages of lithium. The compositions of the three experimental silver solders, together with their melting points and flow points are given in Table I. The test materials brazed were copper and a tungsten-copper alloy containing approximately 70% tungsten. The pieces were butt brazed and then subjected to a cross-breaking strength test consisting in applying the load to a brazed section with the fulcrum at the point of the brazed joint. The brazed specimen was supported on both ends by round supports, the brazed joint being equidistant between the supports, so that the entire load was applied to the joint. The results obtained from these tests showed that brazed joints with lithium-bearing silver solders had a higher cross-breaking strength than the silver solder not containing lithium. It was also found that a lithium content of 0·12 weight per cent. was superior to the higher lithium-content of 0·26 weight per cent. for this particular grade of solder. The test results also indicated that not only higher cross-breaking strength values were obtained, but that the uniformity of the brazed joints was superior with lithium-bearing alloys.

1 *Metals and Alloys*, 1942, vol. 15, No. 6, pp. 962–965.
°METALLURGIA, August, 1941.

In view of the results obtained on joining tungsten-copper and copper with lithium-bearing silver solder, tests were carried out using solders A and B for the joining of nickel, stainless steel (18–8), Monel metal, and a 0·10 carbon steel (S.A.E. 1010) to each other. The brazing procedure was similar to that used for brazing contact materials and the pressure applied during the brazing operation was 100 lb. per sq. in. The tensile strength and cross-breaking strength for the various metals brazed are given in Table II. In all cases the silver solder B tinned the test metals more easily and quickly than silver solder A, this being particularly true in the case of Monel metal and stainless steel. It is also to be noted that the actual strength values for the lithium-bearing alloys fall within a narrow range, thus indicating consistently strong and uniform joints.

TABLE I.
STANDARD AND LITHIUM-BEARING SILVER SOLDERS.

| Type of Silver Solder. | Composition. | | | | Melting Point, °F. | Flow Point, °F. |
	Ag.	Cu.	Zn.	Li.		
A	65·00	20·00	15·00	—	1283	1330
B	65·46	19·50	15·01	0·012	1281	1310
C	65·34	19·66	14·73	0·26	1279	1310

TABLE II.
STRENGTHS OF JOINTS IN VARIOUS METALS AFTER BRAZING.

Base Metal.	Type of Silver Solder.	Tensile Strength, Tons per sq. in.	Cross Breaking Strength, Lb. per sq. in.
Nickel	B	22·2	116,350
	B	22·8	104,300
	B	26·0	112,600
Nickel	A	14·7	76,300
	A	17·5	84,450
	A	18·3	71,500
Stainless steel	B	14·0	94,300
	B	14·9	92,400
Stainless steel	A	13·5	98,400
	A	12·7	83,500
Monel metal	B	21·9	115,000
	B	22·7	109,350
Monel metal	A	16·0	78,200
	A	17·6	89,500
Carbon steel	B	21·5	84,300
	B	21·2	83,900
Carbon steel	A	18·9	74,000
	A	16·1	77,200

To determine the effect of the thickness of the solder film on the strength of the joint, tensile test specimens of cold-rolled steel, 0·10% carbon, were brazed, using the same brazing procedure but applying various pressures in order to produce solder film of varying thicknesses. The brazed specimens were machined, etched with 5% nital solution and the thickness of the solder films measured microscopically with a graduated eyepiece. From the results obtained it was found that the strength reached a maximum of 21·1 tons per sq. in. at a 0·0017 in. thickness of silver solder film containing 0·12% lithium and decreased as the thickness of the film increased, a film of standard silver solder, 0·0037 in. thickness, having a strength of 18·7 tons per sq. in.

Tests were also made with a low melting point silver-copper-zinc-cadmium solder, designated for the purpose of the tests as silver solder D, having a melting and flow point below 1,200° F., and very extensively used on ferrous alloys and nickel base alloys. Comparative tests of solders B and D were made on 18–8 stainless steels, cold-rolled steel, copper, nickel and Monel metal brazed to each other, and on copper joined to tungsten-copper containing 70% tungsten. The test specimens were prepared by placing the solder and flux in position, butting together the samples to be brazed, and then heating the assembly to brazing temperature. At brazing temperature one of the pieces was moved slightly in order to obtain better wetting. Six samples of each of the metals were brazed, varying pressure being applied to the brazed joint while the solder was molten, and being retained until the solder solidified. Two specimens of each metal were silver soldered at 1 lb., 15 lb. and 100 lb. per sq. in. respectively. After machining and etching the silver solder was etched with an etching solution, consisting of sodium chloride, potassium bichromate, and sulphuric acid, and the thickness of the joint measured microscopically.

A comparison of the results obtained indicated that the most consistent results were obtained with lithium-bearing silver solder B. For 0·1% carbon steel both silver solders gave consistent tensile strength values, but the values obtained with cadmium-bearing silver solder D were slightly higher than those obtained with silver solder B. In the brazing of copper to copper, nickel to nickel, copper to tungsten-copper and Monel metal to Monel metal, silver solder B gave the highest and most consistent tensile strength results. Variations in pressures and silver solder joint thicknesses had the least influence on the tensile properties of the joint with silver solder B, which indicated that under varying operating conditions this alloy would provide a reliable and uniformly brazed joint. It was also observed that on all test samples silver solder B flowed more readily and freely than silver solder D.

All the tests carried out show that the new lithium-bearing silver solder is superior so far as fluidity, wetting, and resulting tensile and cross-breaking strength properties are concerned, when compared with some of the standard silver solders, particularly on large brazed sections. This superiority was shown not only in the brazing of copper to tungsten-copper, but also in the brazing of certain ferrous and non-ferrous alloys, being particularly useful in the brazing of nickel or ferrous alloys containing oxidisable constituents, such as chromium, molybdenum and tungsten. Another advantage which the new solder had was that the brazing was carried out without a pre-tinning operation. In addition to the one type of solder discussed, experiments have shown that eutectic silver-copper compositions containing nickel and lithium have definite advantages, and also that a silver solder containing 60% silver, 20% copper, 15% zinc, 4·9% nickel, and 0·1% lithium is extremely promising as a high-strength, high-fluidity brazing medium.

Niobium as an Alloying Element in Heat-Resisting Steels

reduction in the sulphur content to 0·01% leads to a restoration of the creep impeding action of the intermetallic compound.

The actual test data found with a number of 0·2–0·3% Nb steels of varying sulphur content are given hereunder :—

These data show that a reduction in the sulphur percentage exerts an extremely beneficial influence upon the creep strength. Actually, the creep strength of the 0·22% Nb steel with only 0·004% S almost equals that of a steel with a ten times larger Nb content. The notched-bar impact strength of these steels is however but little different from those observed with Nb steels of higher carbon content. It need hardly be pointed out that the 0·38% S steel was included in the table for the sole purpose of demonstrating the influence of the sulphur content per se. In view of the fact that steels with a sulphur content as small as 0·005% are difficult to realise in practice, it is of particular importance to note that only a slight reduction in the creep strength qualities results from accepting a sulphur content of 0·01%, which can be achieved by special methods.

Nothing definite is known as yet with regard to the mechanism of the deleterious influence of the sulphur upon the creep strength ; but it may possibly be due to the formation of a niobium sulphide taking place before the niobium is able to enter into the intermetallic compound with the iron.